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# A Critique of the Scale Method for Determining the Age of the Alewife, *Alosa pseudoharengus* (Wilson)

BRIAN J. ROTHSCHILD

# A Critique of the Scale Method for Determining the Age of the Alewife, *Alosa pseudoharengus* (Wilson)[1]

Brian J. Rothschild
*U. S. Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii*

ABSTRACT

A critical evaluation of the annulus as an index of age in freshwater populations of the alewife has been made. Features of the alewife scale are described. Measurements of annulus position and agreement of ages estimated by the scale method with ages estimated from length–frequency distributions suggest the validity of the annulus as a criterion for estimating alewife age.

## INTRODUCTION

The life history of the alewife, *Alosa pseudoharengus* (Wilson), was studied at Cayuga Lake, New York, during the summers of 1960 and 1961. Age composition of the various alewife samples was required for this study. Individual ages were determined by the scale method. Although several investigators have used the scale method to determine age in freshwater populations of the alewife, no assessment of the validity of the scale method for this species has been made. The purpose of this paper is to evaluate critically the use of scales for determining age of alewives.

## METHODS

Alewife samples were obtained weekly from Taughannock Point and Canoga Island, Cayuga Lake. It was impractical to examine scales from all 5,000 alewives collected during the investigation, so subsampling for scale samples was employed. Total length was chosen as the criterion for subsampling, since a representative sample of fish lengths is likely also to provide a representative sample of their ages. The length–frequency distributions for the samples showed that a large proportion of the alewives were between 111 and 130 millimeters, total length, and that stratification would be required for disproportionate but representative sampling. Thus it was desired to obtain random samples of alewife scales in abundant size strata, and to examine all scales from alewives in the less abundant strata.

Total length strata selected were: 1, less than 111 mm; 2, 111–120 mm; 3, 121–130 mm; and 4, greater than 130 mm. All alewives obtained in total length strata 1 and 4 were scale-sampled and aged. Alewives with total lengths in strata 2 and 3 were assigned numbers in order (1, 2, 3, etc.); then 15 percent of the total numbers of fish in each stratum were selected for scale-sampling and aging using a table of random numbers. Thus each fish scale-sampled and aged from strata 2 and 3 represented in effect 6⅔ fish in subsequent analysis of data.

Scales from various body regions on the alewife were examined. Scales from the midline just above the anal fin insertion were highly uniform with clearly marked annuli. Scales were collected from this region and plastic impressions made. A comparison of plastic impressions with scales mounted dry between two microscope slides revealed that the dry scales produced much better resolution of details when projected.

The subsamples, based on length–frequency distributions of 5,000 alewives, yielded usable scale samples from 2,070 fish. Several scales from each fish were examined on a scale projector, and a representative scale was chosen for measurements. Measurements were made at a magnification of 40.5. Measurements of the distance from the baseline (Cating, 1953) to annuli (annular distance) and to the margin (scale length) were used to study the validity of the annulus as a year mark (June and Roithmayr, 1960). The measurements from the 2,070 scales were arranged in 5-mm size classes, and the frequency and percentage frequency of the annular distances and scale

[1] Condensed from a part of a thesis submitted to the graduate faculty of Cornell University, Ithaca, New York, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

lengths from the postulated 1957 through 1961 year classes were studied. The scale samples from fish taken at the Canoga location added no information beyond that obtainable from the Taughannock samples, so only data from the Taughannock samples (approximately 1,500) are presented in this paper.

## SCALE DESCRIPTION

Alewife scales are typically cluepoid (Cockerell, 1913). They are thin, caducous, cycloid structures arranged in an imbricate fashion. The scales from the midline just anterior to the anal fin insertion are subquadrate in shape. The striated anterior field occupies three-quarters of the scale surface and is separated from the posterior field by a baseline (Cating, 1953), the most posterior transverse groove. The baseline approximately separates the exposed and imbedded portions of the scale.

Sculpture of the scale surface is generally restricted to the anterior field and consists of both transverse and annular markings. Transverse markings run from the dorsolateral edge to the ventrolateral edge of the scale and include transverse grooves and transverse ridges.

Transverse grooves are distinct, well-defined lines, few in number and variably spaced. The grooves are posteriad across the anterior field. This arcing is most pronounced in the more anterior grooves and diminishes until the last groove approximates a straight line (the baseline). The number of transverse grooves seems related to the size of the scales; a large scale from a large Cayuga Lake alewife (130 mm, total length) may have four or five transverse grooves.

Ridges are the numerous transverse markings which roughly parallel the anterior edge of the scale. There may be as many as 70 ridges normal to an imaginary line from the center of the baseline to the anteriormost portion of the first annulus. Ridges are often discontinuous and may terminate, branch, or be interrupted anywhere on the scale surface. Discontinuities are particularly common at scale-erosion sites, along the antero–postero–medial portion of the scale surface, and where the ridges are intercepted by transverse grooves or annular marks.

Annular features of the alewife scale include growth zones and rings or checks. Growth zones appear as alternate light and dark regions which parallel the scale edge and result from localized thinning and thickening of ridges. Zones are not evident in the posterior field, and in some fish are not present on all scales.

Annuli are nonambiguous rings or checks which under low magnification (less than 40 ×) appear in the anterior field as fine lines cutting across both ridges and transverse grooves. Annuli are continuous in the anterior field and are often evident in the posterior field as bands of increased optical density. High magnification reveals that an annulus is formed either by localized constriction or interruption of ridges. The lateral continuation of an interrupted ridge may be slightly displaced or at an angle different from that of the ridge before interruption. Annulus formation seems to occur during the spawning period, and as a consequence annuli and spawning marks merge in mature fish. Immature fish appear to form an annulus at the same time of year as the mature fish do. Cating (1953) gave a similar interpretation to the annulus of American shad, *Alosa sapidissima*, which was later verified by tagging studies (Judy, 1962).

Recognition of an annulus on the scale margin involved a degree of subjectivity. Marginal annuli first appear as sites of erosion on the scale margin at the juncture of the anterior and posterior fields. Erosion seems to proceed anteriorly along the scale margin, and the eroded parts of the margin can be distinguished by the terminal ends of the marginal ridges. In an uneroded margin the termination of each ridge appears acutely pointed, with the apex of each point on the margin; with the onset of erosion the pointed ridge termination becomes truncate. Truncated ridges appear to be connected by a fine line, possibly an optical artifact. At times a hyaline border is evident, and its margin along the line connecting the truncated ridges gives the appearance of double parallel lines. A marginal annulus on the anterior scale margin may be an indistinct fine line, sometimes crenate and often invested in minute granulations.

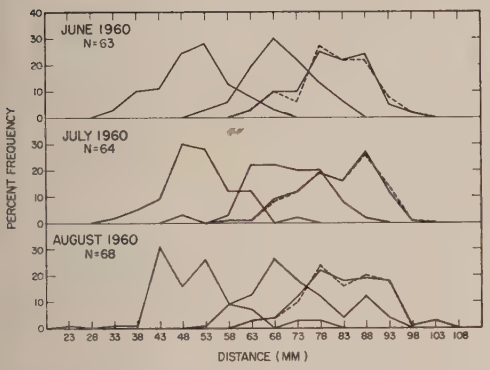


FIGURE 1.—Percent frequency distributions of the distances in millimeters from the baselines to annuli (solid line) and scale margins (broken line) of scales from alewives collected at Taughannock Point in 1960 and assigned to the 1957 year class.

One year of age was assigned for each annulus on the scale surface. An additional year was assigned if the marginal annulus was well defined or, when the marginal annulus was uncertain, if there was a large growth increment beyond the preceding annulus.

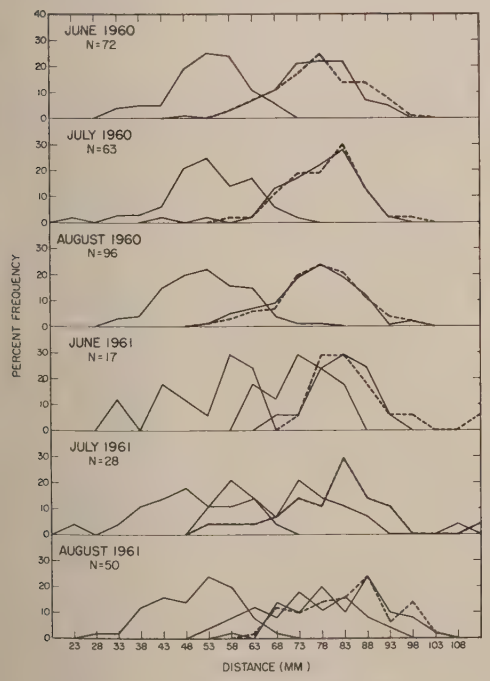


FIGURE 2.—Percent frequency distributions of the distances in millimeters from baselines to annuli (solid line) and scale margins (broken line) of scales from alewives collected at Taughannock Point in 1960–61 and assigned to the 1958 year class.

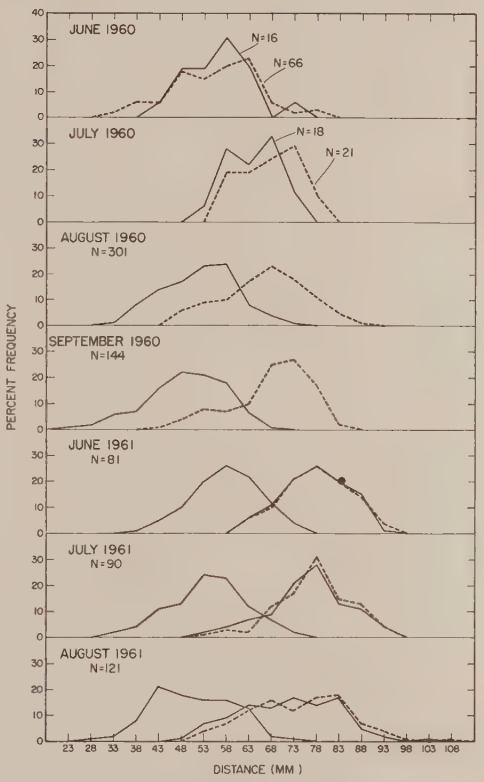


FIGURE 3.—Percent frequency distributions of the distances in millimeters from baselines to annuli (solid line) and scale margins (broken line) of scales from alewives collected at Taughannock Point in 1960–61 and assigned to the 1959 year class.

## SCALE MEASUREMENTS

Percent frequency distributions of the distance from the baseline to annuli and scale margin for various postulated year classes of alewives are presented in Figures 1–5. The figures indicate that annuli are formed each year on the margin of the preceding year's scale growth, that annuli are not formed before the first anniversary of life, and that annulus formation is evident on the scale margins in early summer.

Early summer annulus formation was particularly evident in samples of the 1959 year class taken in 1960 (Figure 3). Only 16 of the 66 fish sampled in June had an annulus,

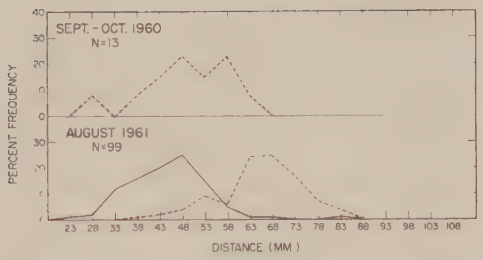


FIGURE 4.—Percent frequency distributions of the distances in millimeters from baselines to annuli (solid line) and scale margins (broken line) of scales from alewives collected at Taughannock Point in 1960–61 and assigned to the 1960 year class.

but 18 of the 21 sampled in July and all 301 alewives sampled in August had an annulus. Marginal scale increments increased with time in younger fish, but this increase was not quite as apparent in older fish. Difficulty in determining time of annulus formation and detecting scale growth may be due to sampling too short a time period, to scale erosion, and to slow growth of older fish.

Overlap and variability in the percent frequency distributions can be attributed to several sources. Some overlap can be attributed to the stratification procedure, which includes a greater proportion of "large" and "small" fish in the subsample than is actually present in the statistical population. Disproportionate numbers of extreme-sized fish will cause disproportionately high numbers of extreme scale measurements because fish size and annular measurements are correlated. Extreme values in small, highly variable samples are given greater weight than extreme values from large samples because of use of percent frequencies. Since the mode and position of each distribution are used as criteria for validity, overlap is not a serious consideration.

Sources of variability are also evident in

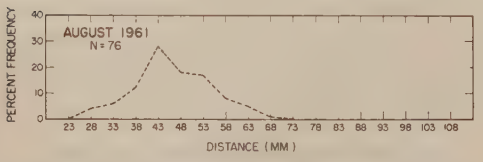


FIGURE 5.—Percent frequency distribution of the distances in millimeters from baselines to scale margins of scales from alewives collected at Taughannock Point in 1961 and assigned to the 1961 year class.

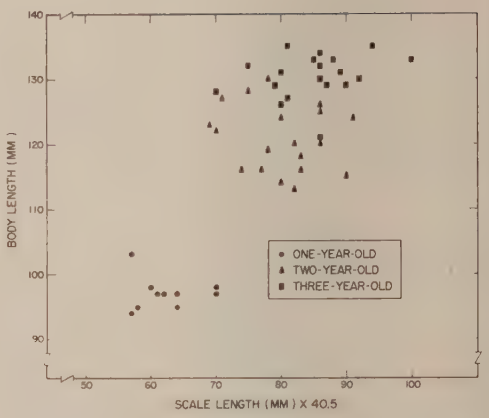


FIGURE 6.—Relation of total body lengths in millimeters to scale lengths in millimeters $\times$ 40.5 for various age groups; sample taken at Taughannock Point on July 9, 1960.

scale length–body length and scale length–annular distance relations. Figure 6 shows the correlation between scale length and body length for alewives collected on July 9, 1960. There is a moderate degree of scatter. Body length is a better index of age than scale length.

The scale length–annular distance relation is demonstrated in Figure 7, which shows that scale length and marginal distances are correlated. Each annulus group forms a distinct cluster of points, which further attests to the uniqueness of each annulus. Body length, scale length, and annular distance are all correlated.

## RELATION OF ASSIGNED AGE TO LENGTH–FREQUENCY DISTRIBUTION

Plots of the length–frequency distributions could be separated into component modal groups. Three component groups were distinguishable. The first modal group appeared in late summer; these fish were about 10 to 85 mm long and were postulated to be young-of-the-year. A second modal group with lengths ranging from 80 to 110 mm was apparent in some of the samples, and these fish were postulated to be 1-year-old fish. A third modal group consisted of alewives greater than 110 mm in total length which were postulated to be 2 years old and older. An underlying polymodality of fish lengths in the third modal group was masked by a disproportionately

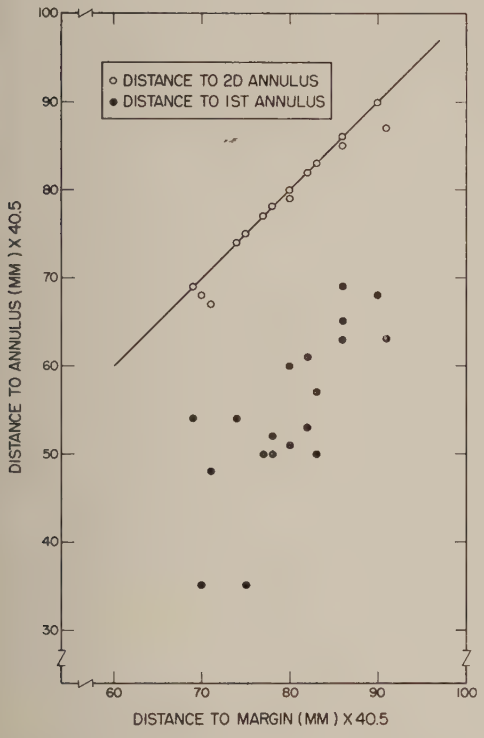


FIGURE 7.—Relation of annular distances in millimeters × 40.5 to scale lengths in millimeters × 40.5 for 2-year-old alewives taken at Taughannock Point on July 9, 1960. The diagonal line indicates equal marginal and annular distances.

large number of 2-year-old fish in the samples. It is important to note that near the end of the summer recruitment into larger size groups may take place.

Scale examinations revealed that fish in the size range of postulated 1-year-old fish have one annulus or are forming an annulus (Figure 3). Postulated young-of-the-year had no annulus (Figures 4 and 5). The large modal group with total lengths greater than 110 mm is composed of alewives with two, three, and four annuli. Fish with no annuli are smaller on the average than fish with one annulus, etc. Overlap in size of older age groups contributes to the apparent unimodality among fish greater than 110 mm. Agreement between assigned ages and length–frequency distributions suggests validity of the annulus as a year mark.

## DISCUSSION

Distribution of annulus positions conforms with empirical growth patterns; *viz.*, growth rate decreases with age and the distance between annuli also decreases with age. Distributions of annuli for particular year classes and locations have a relatively constant position over all sampling months and years. Constant annulus position implies that each annulus is a unique entity throughout the life of the alewife. The modal annular distance for each successive annulus is greater than the annular distance of the preceding annulus, and increments between successive annuli decrease in length with the number of annuli. Despite sources of variability, the pattern of postulated annulus deposition and the agreement of assigned age with age inferred from total length–frequency distribution suggest that the annulus as herein described is a valid criterion for estimating age in freshwater populations of the alewife.

## ACKNOWLEDGMENTS

The suggestions and advice of Dr. E. C. Raney and Dr. D. S. Robson of Cornell University are gratefully acknowledged. James Reckahn, also of Cornell University, was particularly helpful in collecting specimens. This work was supported by National Science Foundation Grant 8909.

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# Graphic Comparisons of Meristic Data

Brian J. Rothschild

**Graphic comparisons of meristic data are discussed. The usual presentation of graphic analysis is similar to the form proposed by Hubbs and Perlmutter. Methods of presentation may be uncritical and the procedure itself is subject to inherent statistical weaknesses. The presentation is strengthened by utilizing Tukey's multiple comparison procedure. Tukey's procedure has a fixed range and can be presented graphically.**

THE objective of this paper is to propose an alternative to the graphical method of comparing meristic data proposed by Hubbs and Hubbs (1953), a modification of that of Hubbs and Perlmutter (1942), which is often used uncritically. The graphical method is commonly utilized in systematic zoology as a demonstration of statistical variation among samples. The mean and two standard errors on each side of the mean are plotted, giving for each sample a rectangle four standard errors long. The degree of overlap between the rectangles associated with pairs of means is then adjudged for significance by an analogue to the large-sample $t$ test. Historical and controversial aspects of graphical analysis have been dealt with in various works, e.g., Hubbs and Perlmutter (1942) and Simpson, Roe, and Lewontin (1960:350–8).

Many authors use the graphical method to present their data but omit statistical interpretations. Inclusion of rectangles four standard errors long could be taken to imply that statistical tests have been or are to be made. It is often not clear which, if either, implication is intended. The nature of any tests which might be applicable, and the degree to which the assumptions associated with such tests are approximated are likewise frequently not made clear. This inadequate exposition by authors forces readers to assume that graphical presentations are to be interpreted according to Hubbs and Hubbs (1953).

Uncritical use of the graphical method is exemplified when some of its basic requisites, as prescribed by Hubbs and Hubbs, are ignored. An example would be the use of "small" sample sizes in the "large-sample" $t$ test. An inherent statistical weakness is demonstrated by the fact that often the procedure is not based on a minimum possible variance. Furthermore, the diagrams strongly suggest that each mean may be contrasted with every other mean by a reasonable statistical procedure. Such a suggestion is misleading, because if all possible pairs of means are compared, the resulting comparisons cannot be independent of one another (see, for example, Snedecor, 1956:251, or Fraser, 1958:284–7). If they are not independent, the error rate is not fixed at the approximate 1% or 5% level, for example, but varies as a complicated function of, among other things, the nature of the data, the degree to which the comparisons are correlated, and the number of comparisons. In other words, the level of significance under which the test is being performed is unknown. If the level of significance is unknown, then it is difficult to place confidence in conclusions drawn from such a test.

In some cases multiple-comparison procedures, by which all possible comparisons can validly be made, may be suitable for meristic-data analysis. Many nongraphic procedures of this kind are satisfactory for dealing with a wide variety of meristic problems and are available in standard textbooks, e.g., Snedecor (1956:251–3), Steele and Torrie (1960:106–12). Lund (1961) used Duncan's New Multiple Range Test (Duncan, 1955, 1957) for comparing the mean number of soft dorsal rays in the bluefish (*Pomatomus saltatrix*), and Mansueti (1961:178) expanded the graphic pre-

sentation of the same test in a comparison of meristic indices of the white perch (*Roccus americanus*).

Graphic methods restrict the investigator to a narrower spectrum of analysis, but they provide good data summaries, excellent demonstrations of clinal situations, and a résumé of the population characteristics. It is possible to retain these advantages by using a multiple-comparison procedure which has a fixed range. Tukey's procedure (Steele and Torrie, 1960:109–10; Snedecor, 1956:251–3) has a fixed range and can be presented graphically.

A first step in Tukey's procedure is an analysis of variance, so the investigator must make sure his data conform with the assumptions requisite for the analysis, as discussed in detail by Eisenhart (1947) and in some statistics texts. One of the assumptions that must be satisfied is that of a normal distribution, based on continuously distributed variables. Meristic data are, however, distributed as discrete variables, so the best an investigator can do is to approximate a normal distribution. A reasonable approximation of normality is attained when sample size is at least "moderate" (i.e., about 30), the data range over several counts, and the distribution of counts has some degree of symmetry. As sample sizes increase, the distribution will usually tend to approximate normality more closely.

Tukey's procedure requires samples of equal size. When sample sizes are unequal, one alternative is to use a conjectured approximation presented by Steele and Torrie (1960:114). This is not, however, convenient for graphical presentation, and therefore random subsampling of the original samples is suggested. It may be argued that the subsampling approach disregards information from the discarded samples. This consideration is important only when extreme precision is required or when sample sizes are very small. In either case sampling should be implemented. If the sampling cannot be implemented, then recourse to other procedures is indicated.

Performance of the analysis of variance will yield a significant or nonsignificant $F$ value at a level specified by the investigator. If $F$ is nonsignificant, there is no evidence that the means are drawn from unlike populations and the testing procedure is terminated. However, if $F$ is significant, then the investigator should determine which means

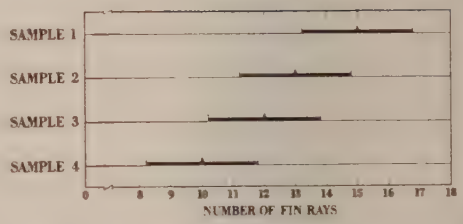


Fig. 1. Hypothetical means and intervals for determining significance between all six possible comparisons of means.

are drawn from heterogeneous statistical populations. These may be identified by use of Tukey's procedure, which establishes an interval about a mean; this interval is used to establish whether other means are significantly or not significantly different from the first mean. The length of one-half the interval ($w$) is given by Steele and Torrie (1960:110) as

$$w = q_\alpha (p, n_2) s_{\bar{x}}$$

- $q_\alpha$ is the upper percentage point of the studentized range at the $\alpha$ significance level and is tabled in Steele and Torrie (1960:444) and Snedecor (1956:252).
- $p$ is the number of samples.
- $n_2$ is the error degrees of freedom.
- $s_{\bar{x}}$ is the pooled standard error of the sample means.

A hypothetical example follows: Suppose there are four samples of fish with mean ray counts of 15, 13, 12, 10 with $s_{\bar{x}} = 0.5$ and there are 25 fish in each sample with $p = 4$. An $F$ test is performed and significance is established at the $\alpha$ level. There are 96 degrees of freedom for the error term. The term $q_\alpha$ is determined from tables for $\alpha = 0.05$ as 3.7. Therefore

$$w = 3.7\ (0.5)\ = 1.85$$

The means and the $2w$ intervals are plotted in Figure 1. If a mean is within the range of $2w$ for any sample, then it is not significantly different from the mean of that sample. On the other hand, if a mean is not within the range of $2w$, then it is judged significantly different from that mean. For example, sample 4 is significantly different at the 5% level from sample 3; samples 3 and 2 are not significantly different; samples 1 and 2 are significantly different, etc. All possible comparisons can be made validly by this method.

Ranges can be included in the diagrams. Inclusion of sample standard deviation is a matter of personal preference since by assumption sample standard deviations estimate the same population sample deviation and the best estimate of the population standard deviation is given by the square root of the error sum of squares in the analysis of variance.

This paper is not intended to discourage the Hubbs–Perlmutter type of presentation but rather to implement its use. It is immediately apparent that graphical methods can neither ameliorate poor data nor replace computations based on founded statistical assumptions. The graphical method of Hubbs and Perlmutter is an excellent demonstration of means and variation of means for a series of meristic counts. When utilized for statistical comparisons, the graphical procedure has both statistical and interpretive inadequacies. The advantages of the graphical method can be retained and the statistical inadequacy can be alleviated by employing Tukey's procedure in the graphical method.

Discussions with professors D. S. Robson and E. C. Raney of Cornell University, Ithaca, New York, have been helpful in writing this paper. Much of the work was supported by National Science Foundation Grant 8909. To Dr. Milner B. Schaefer of the Inter-American Tropical Tuna Commission, Dr. William E. Ricker of the Fisheries Research Board of Canada, and Dr. Albert L. Tester of the University of Hawaii, who read this paper in draft, the author wishes to express his thanks for their thoughtful criticisms without, however, imputing to them the views contained in the paper, which are, of course, the author's own.

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Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.

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PINK SALMON (*Oncorhynchus gorbuscha*) IN NORTHERN NORWAY IN THE YEAR 1960. *By Magnus Berg. (Acta Borealia; A: Scientia No. 17). Tromsø Museum, Tromsø, Norway. 1961. 24 pp. [In English, Norwegian résumé.]*

This is an account of the appearance in Norwegian waters in 1960 of large (sic) numbers of pink salmon from fry released by the Russians. Mention is made also of catches in Iceland and Scotland. Pink salmon catches were reported as far south as Bergen, but were especially great in Finmark. The total catch is estimated at 20,000 to 25,000 kilos.

Unfortunately, there are several features of the account that seem questionable. Although the author states that pink salmon are easily distinguished from other salmon by "little scales and the dark spots on the tail," we note in Figure 2 that the drawing of a pink salmon fry is labeled *O. keta*, and that of a chum salmon, *O. gorbuscha*. The source of the material drawn is not mentioned. The author is apparently unfamiliar with the classification of fishes, since he states concerning Pacific salmons, "None of these fish are the same as the Atlantic salmon *Salmo salar*, and they belong to quite another family of fish." The arctic charr, *Salvelinus alpinus*, he calls *Salmo alpinus*, and *tshawytscha* is given the older spelling of *tschawytscha*.

Because most of the fishermen and fish buyers did not separate pink and Atlantic salmon of less than 3 kilograms, his best source of information on catches was from a single firm.

Although numbers of pink salmon undoubtedly were taken in Norway, this reviewer notes either more than one species of Pacific salmon was involved, or these pink salmon differ considerably in both habits and size from their forebears in the Pacific. For example, the author mentions a pink salmon of 3.5 kilos (7.7 pounds) which is extremely large for a pink, the record in the eastern Pacific over many years and millions of fish being around 10 pounds. He states that "The pink were fished with the usual baits, worms, or wet tinbait, or fly. It is a good sporting fish." In regard to this statement and numerous other references to taking of these pink salmon by angling, I would like to mention that I have fished for trout using fish roe, spinners, and wet flies in streams abounding in pink salmon from Unalaska to Puget Sound without taking a single pink salmon. In Lake Superior, however, two pink salmon from a small, recently established run were taken by anglers on earthworms in the estuaries of two tributary streams (Schumacher and Hale, Trans. Am. Fish. Soc., 1962, 91: 421–422). This could be the result of no drastic change in environment such as occurs when salmon leave the ocean to enter a stream. Thus, the pink salmon that were established for a few generations in the Dennys River in eastern Maine during the early 1920's were not taken by anglers fishing the same waters for Atlantic salmon.

The author also states that pinks ascended the river Anarjokka 300 kilometers from the sea. In only a few streams in North America do pink salmon make a comparable journey. The Russians have been transplanting both pink and chum salmon since 1956 and made earlier attempts with chum salmon from 1933 to 1939, leaving considerable doubt in the mind of the reviewer that all of the salmon reported as pinks were in fact pinks.

GEORGE A. ROUNSEFELL

*U. S. Bureau of Commercial Fisheries*
*Biological Laboratory*
*Galveston, Texas*

# SAVANNAH ESTUARY ENVIRONMENTAL RADIOLOGICAL SURVEY (SEERS) PROJECT

by
Julius J. Sabo,[1] John P. Baptist[2], and Fred G. Rueter[3]

## Introduction and Problem

At present, the coastal waters of the United States are being used and no doubt will continue to be used as the receiving media for radioactive wastes discharged from nuclear installations based on land and from those based on marine vessels. Generally the quality of the coastal waters has not been too adversely altered by many of the man-made wastes which usually find their way into these waters; their quality, however, could be seriously affected by receiving radioactive wastes which could create a radiological hazard not only to the aquatic environment but also to man himself.

The United States Navy has several nuclear-powered vessels, all of which use estuarial and other inshore waters. Present operational plans seem to indicate that the nuclear-powered ship, NS Savannah, will sail not only in the coastal waters but also in certain navigable estuaries. The probability is great that more nuclear-powered vessels will become commissioned, and that more land-based nuclear installations will be located near the ocean. If the radioactive wastes from all these nuclear power plants should enter the marine environment, what will be the changes effected upon this environment? What methods can be used to measure these changes? What will be the ecological significance of these changes? How can these receiving waters be used sanitarily to accept the radioactive wastes? These and many other questions should be answered before any significant nuclear program be undertaken near the coastal areas.

The present symposium has been arranged not only to seek answers for the questions just asked, but also to discuss

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[1] Senior Sanitary Engineer and Project Officer for the SEERS Project, Division of Radiological Health, Public Health Service

[2] Marine Biologist, Fish and Wildlife Service, Bureau of Commercial Fisheries

[3] Assistant Sanitary Engineer, Division of Radiological Health, Public Health Service

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the radiological aspects of estuaries in general and the Savannah River Estuary in particular. Many radiological studies of an aquatic environment have been conducted, but only a few have dealt with estuaries. The Division of Radiological Health, Public Health Service, has many aims that it desires to accomplish by guiding a cooperative radiological survey and study of the Savannah Estuary. A cooperative project, such as this Savannah study, is desirable in order to obtain useful data with a minimum of effort. The analysis of water, sediments, and seafood by the Public Health Service;[4] the study of silt deposition and tidal flow by the Corps of Engineers; and the ecological studies by the Bureau of Commercial Fisheries will together contribute more data as to what is occurring in the estuary than could be contributed by any one of these agencies It is by such mutual exchanges of ideas and interests that these agencies will be able to accomplish many of their aims and ultimately effect methods which will enable investigators to enter an area where a nuclear incident has occurred and evaluate quickly the extent of radioactive contamination.

The Savannah project represents one of the few radiological estuarial studies conducted by the Division of Radiological Health (DRH), PHS. For this reason, we of the Division can relate only what we have so far accomplished by the current survey of the Savannah Estuary and what we plan to do in the survey. The general reason for conducting a radiological study of the estuary is that the Savannah River Plant, a nuclear facility located on the banks of the Savannah River approximately 130 miles upstream from the estuary, discharges some of its liquid radioactive wastes directly into the river. We are concerned with how much of these will reach the estuary, an active fishery, and what ecological influences the wastes will have upon the estuarial aquatic environment.

## Purpose of Radiological Study

The specific purposes for which this estuarial project has been designed are the following:

1. The establishment of baseline radiation levels to which future radiation levels of the Savannah Estuary can be referred. Such a baseline could be used as part of a monitoring system designed

[4] The collection of the various marine samples was made possible by the use of boats provided and manned by U. S. Coast Guard personnel stationed at Savannah, Ga.

to aid in controlling the radiation levels of this marine environment.

2. The derivation of data which can be used to determine the fate of radionuclides in marine waters and which can be used to develop mechanisms capable of removing radionuclides from these waters.

3. The determination of appropriate indicator organisms or other organic materials which can be used in measuring the concentration of radionuclides present in a marine environment.

4. The ascertainment of the effect of radioactive wastes on the fisheries industries.

It is the contention of radiobiologists associated with the Bureau of Commercial Fisheries that on-site natural radiological studies are needed to corroborate laboratory studies. The Savannah Estuary study seems to afford the opportunity for such a corroboration. One can almost consider this aspect as the fifth purpose for conducting the proposed estuarial program.

## Scope of Study

Radiobiologists, in general, are convinced that ecology is an integral element in radiological investigations of estuaries, mainly because estuaries are generally so complex, with thousands of species of organisms living in many different habitats. These species include swimming organisms, plankton, and the benthic organisms.

Progress in ecological studies concerned with radiological aspects has been made by several investigators. Their field and laboratory studies have yielded much useful data on the fate of many radionuclides associated with the aquatic environment. Davis et al. (5) found that suckers in the Columbia River which fed on sessile algae accumulated more radioelements than did other fish of higher trophic levels. The distribution of $Cs^{137}$ has been traced through a fresh water community by Pendleton and Hansen (6). Baptist and Price (2) demonstrated that the growth rate of flounders influenced the rate of $Cs^{137}$ uptake as based on a unit weight of the organisms. Boroughs et al. (3) reported that postlarval flounders accumulated $Sr^{89}$ at a faster rate at 20° C than at 10° C. The use of biological indicators to indicate the presence of radionuclides which

otherwise would not be detectable in the environment has been suggested by Rice and others (10, 11).

The Savannah Estuary, as indicated by figure 1, is a very large and complex system of meandering creeks. Many of the creeks, being contiguous with the river, could receive radioactive wastes should such wastes be present in the river. Fifteen tentative sampling stations have been selected, their choice being based on either ecological or radiological concepts or both. Four of these stations are on the river proper. Other stations are located on many of the smaller creeks, which are highly productive biologically; some are active shrimp nursery areas. Some stations were selected to include areas of either high or low salinity. The South Channel contains a spoil area which receives sediments from the dredged channel. A station near this spoil area was considered to be a good choice for the collection of bottom organisms.

The modus operandi for the ecological study of the Savannah Estuary follows a plan based largely upon advice given by the Bureau of Commercial Fisheries. Such a plan is desired for conducting radiological studies of the following:

1. Water
2. Intertidal region
3. Plankton
4. Swimming organisms
5. Bottom organisms and associated sediments

Similar radiological studies of a control area are being conducted simultaneously with the Savannah studies so that proper evaluations of the latter can be made. The control area is represented by the estuarial waters located at Edisto Beach, North Carolina, about 60 miles northward from the Savannah Estuary.

## Water Study

Water characteristics such as dissolved oxygen, nutrient content, temperature, radioactive content, turbidity, and salinity are known to affect the accumulation of radionuclides by aquatic organisms. For example, some organisms are known to accumulate radionuclides faster at high temperatures than at low temperatures; oysters have been found to accumulate smaller amounts of radioelements when salinities were above or below the normal range;[5] radioactive uptake by some

[5] Unpublished data derived by Thomas J. Price, Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N. C.

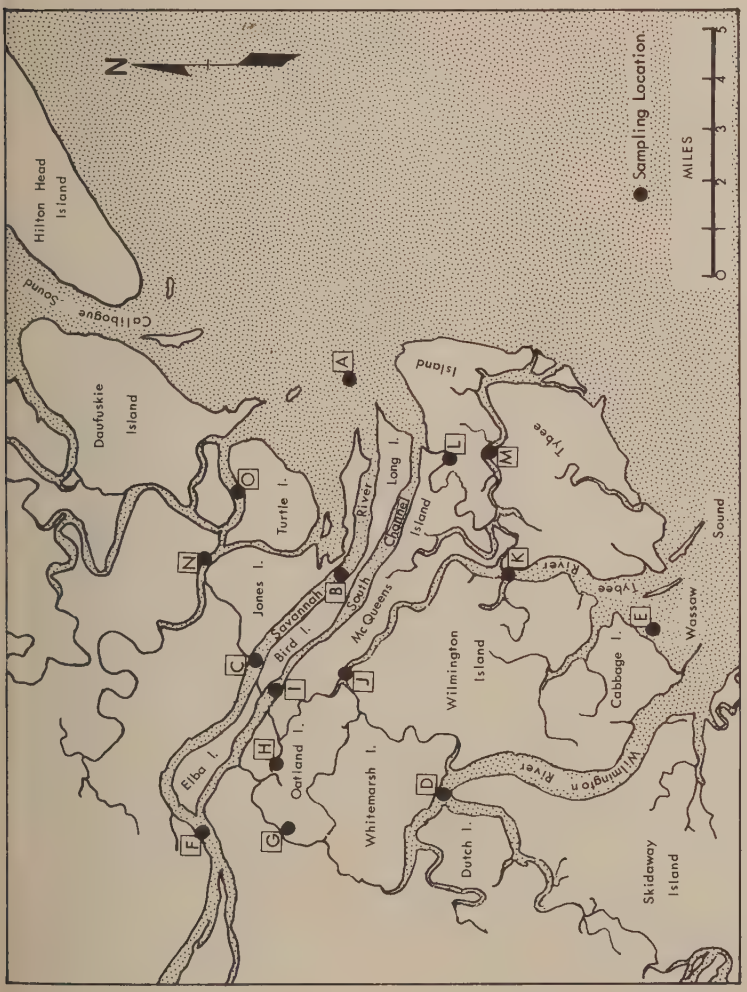


Figure 1.-Location of Sampling Stations in the Savannah Estuary

phytoplankton is so influenced by turbidity interferences, which affect photosynthesis, that the rate of planktonic cell division is altered. Similarly, the lack of nutrients can limit phytoplankton production and result in a decrease in the rate of removal of certain radionuclides from the water. The dissolved oxygen content of water determines to what extent the water will support life. Oxygen determinations, therefore, are important in tracing the cycling of radionuclides in the aquatic environment. Pertinent hydrological data collected by the Corps of Engineers are also being utilized to aid in the explanation of this cycling.

Water samples are sent to SERHL[6] where their suspended and dissolved solids are isolated so that the radioactive content of each group can be determined. Dissolved solids are analyzed by methods of chemical separation. Analyses of the other water characteristics are made by the Bureau of Commercial Fisheries at its laboratory located at Beaufort, North Carolina.

## Intertidal Study

The intertidal region offers much to be studied that is not found in the subtidal region. Since intertidal organisms such as oysters, clams, seaweed, and microscopic algae are alternately exposed to water and air during the tidal cycle, they might be expected to effect less radioactive uptake than organisms which are continuously exposed to water. However, their usefulness as indicators of radioactive contamination is enhanced by their being predominantly sessile and easily accessible for examination (see figure 2). Tentative plans have been made to investigate the estuarine communities of organisms inhabiting rock jetties, dock pilings, sand bars, and oyster reefs. Organisms of the tidal zone are probably instrumental in the transmission of radionuclides through certain food chains. During high tide, active animals such as fishes and crabs move into the tidal zones in search of food. During low tide, terrestrial animals such as mink, rats, and skunks feed on these tidal organisms. Thus, tidal zones are involved in the food chains of two different environments.

Oysters, which are major organisms in the intertidal region have been sampled and analyzed after being separated into flesh and shell components (figure 3). This separation was necessary because the flesh had a radioactive content which was much greater than that of the shell; all of the shells contained less than 2.4 pc/g ash. Further, the oyster flesh was more easily analyzed separately than in combination with the shell. Before oysters were sent to SERHL for analysis, they were prepared in the field in accordance with the following procedure:

1. Oyster shells were wire-brushed clean of algae and mud.

2. Oysters were then pried open and the mantle liquid was drained and discarded.

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[6] Southeastern Radiological Health Laboratory, Montgomery, Ala. This laboratory is operated by the Division of Radiological Health, Public Health Service.

Figure 2.-Collection of Oysters from One of Several Sampling Sites Along the Savannah River in the Estuarine Area

3. The oyster flesh together with the body liquids were shucked into a polyethylene bottle containing a 70 percent ethyl alcohol preservative. All organic samples were so preserved.

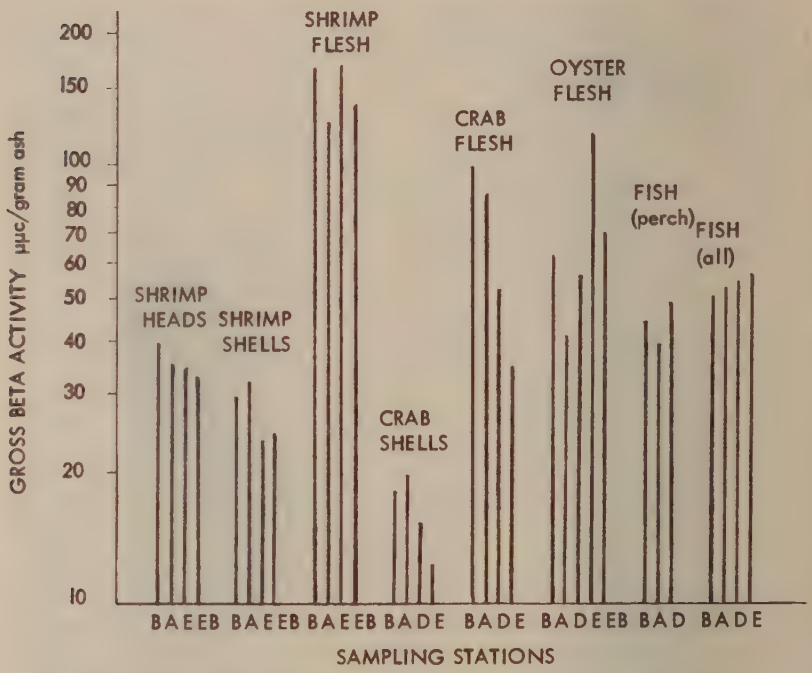


Figure 3.-Gross Beta Radiation Levels for Various Organisms Collected from the Savannah Estuary at the Designated Sampling Stations (NOTE: Some organisms were analyzed in their entirety; others were analyzed in their separate parts.)

## Plankton Study

Plankton are of great importance because of their position at the beginning of food chains and because of their capacity for concentrating most radionuclides. Phytoplankton, being autotrophic, obtain nutrients from the water and are able to produce energy through the process of photosynthesis. Phytoplankton are fed upon by shellfish and zooplankton, the former representing a single link in the food chain extending from a primary producer to a seafood organism. Fish, according to their species, may represent the second, third, or fourth link of the food chain.

Identification and enumeration of phytoplankton is accomplished by microscopic examination of measured volumes of

the sampled water. This method yields a quantitative count; other methods are gravimetric and probably will not be effective because of the presence of considerable silt associated with the water. Identification of plankton is more important than may appear, since some are known to concentrate $Sr^{89}$ about 100 times more than others (9). Thus, by knowing which plankton species predominate in an area, one can make an approximate prediction as to which nuclides will be available to other organisms. Zooplankton, including larval forms of insects, molluscks, crustaceans, fish eggs, etc., accumulate radionuclides by feeding primarily on phytoplankton and on the dissolved nutrients present in the ambient water. Rice and Murdoch (11) reported concentration factors of 200 for $Zn^{65}$ and approximately 600 for $Ce^{144}$ in the copepod, Tigriopus. They also reported that Artemia accumulated 2.6 times more $Zn^{65}$ from food than from water and 7.5 times more $Co^{56, 57, 58}$ from food than from water. Thus, zooplankton have two pathways of accumulation, and since they are food for primary carnivores of the third tropic level, zooplankton play a very important part in the transmission of radionuclides.

## Swimming Organisms

The study of swimming organisms has been underway at some stations. Organisms of many species have been collected for radiological analysis and have also included non swimmers such as sponges, corals, starfish, jellyfish, squid, and other organisms that were present in sufficient number so as to comprise a radiological sample (see figures 4 and 5). It is hoped that this collection approach might lead to the discovery of suitable biological indicators which can be used to measure local radioactive contamination. At the present time, such indicators include fish shorter than 6 inches, shrimp younger than 6 months, and blue crabs. To measure the radioactive contamination of a general aquatic area, shrimp older than 6 months and large fish may be used as the indicators.

It has been found from examinations made by the Public Health Service (graphed in figure 3) that fish can be effectively radioassayed in their entirety. Shrimp, however, have to be divided into three portions: the head with viscera, the flesh, and the shell, since the flesh portion was found to contain more radioactivity per gram of ash than the other portions of the animal. Further, the ashed flesh represented less than 20 percent of the total ashed weight; therefore, the high radioactive

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Figure 4.-Men, Boat, and Sampling Equipment Used in the Collection of Marine Samples from the Offshore Waters

concentration found in the flesh would have been diluted had the shrimp been analyzed in its entirety. For this reason it is considered that the shrimp flesh is a more sensitive indicator than the whole shrimp. A similar finding was made in the case of crabs (primarily blue crabs). The crabs were

Figure 5.-Collection of Fish from the Deep Offshore Waters

steamed before ashing because the steamed crab flesh was easier to handle and easier to separate from the shell than the raw flesh. The ashed weight of the steamed crab flesh was found to be about 15 percent of the total ashed crab weight, while the activity per gram of ashed flesh was more than 3 times that of the shell portion; hence, the flesh alone seems to be the better indicator.

Stomach contents of the various organisms have not been examined, but they will be in order to obtain food chain data which can probably be related to the transmission of radionuclides. Examination of the contents from the digestive tracts of organisms is most useful in identifying the food eaten by the organisms; however, unless the animal is examined soon after it has eaten, identification of the ingested forms is extremely difficult. By examining large numbers of specimens at different times this difficulty may be overcome to some extent. Fish of certain species are known to change their food habits during their developmental phases. For example, the menhaden (Brevoortia tyrannus) is a filter feeder in the juvenile and adult stages, but a particulate feeder in the larval stage (4).

Since the growth rate of an organism affects its uptake of radionuclides, such rates are needed for the various species in order to evaluate properly the radiobiological findings. Animals with fast growth rates tend to show decreased amounts of radioactive material per unit weight by reason of "biological dilution" if the material is not essential for metabolism (2).

## Benthic Organisms and Sediments

The role of benthic organisms in the cycling of radionuclides is closely related to the bottom sediments, which rapidly accumulate certain radionuclides. For example, Pendleton and Hanson (6) reported that a large part of the $Cs^{137}$ in an aquatic community was adsorbed on the sediments. Many benthic organisms such as worms and crustaceans ingest sediments and hence radionuclides along with their food. Anderson et al. (1) reported considerable amounts of clay in the guts of mullets, anchovies, and menhaden. Shellfish are especially susceptible to radioactive contamination since radioactive material is available to them from water, plankton, and the substrata.

Since the type of bottom material helps to control the benthic animal communities, sediments have been collected and screened in order to collect the organisms present. Some silts and bottom muds have been separated into their various size fractions for radiological examination. The fractions below the 60 micron (μ) size were separated by sedimentation, whereas fractions above this size were separated by wet sievin The size fractions so prepared were then sent to SERHL for analysis. All sieving and separation were accomplished hydraulically as described in the following paragraphs.

Collection of bottom muds was made with an Eckman dredge, which so far has shown satisfactory performance. Ten to 15 gallons of water, hereinafter referred to as "local" water, were collected with each of these mud samples and from approximately the same sites as those of the muds. Until such time as they could be analyzed, each mud sample, moistened with a sufficient amount of its local water, was stored in a sealed polyethylene container. There might be some interest in obtaining bottom mud cores to see if a gradient of radioactivity versus mud depth does exist. Such a gradient is expected not to be present in situ in freshly mixed muds and silts; however, in areas where recent mixing has not taken place, the movement of radionuclides through the sediment might establish an activity gradient.

The wet sieving process, shown schematically in figure 6, was conducted on a few sampled sediments by placing the sediment on the topmost sieve and then washing the sediment with its local water through each of the sieves until separation was complete and sediment particles of less than 60μ size were left in the mud-water reservoir. A recycle pump was used for the complete washing of the sediment. Local water only was used for the washing so as to preserve as much as possible the in situ characteristics of the clays, silts, and flocculents that are usually present in muds. In the actual sieving, the mud sample was not washed through a series of fixed sieves, but was washed through succeeding sieves with each sieve being used singly because the agitation required for sieving was more effectively applied with the single sieve than with the stacked series. Table 1 lists the serial gradations for the standard mesh sieve sizes. The Wentworth Particle Size Designation is one of the established classifications relating the size designation to a size term.

The material remaining on the 3.3 millimeter (mm) and 2.0 mm screens (mesh 6 and mesh 9 sieves) was discarded because it usually consisted of shell fragments, driftwood, and other organic material. The materials which remained on the other screens, after each complete washing, were transferred to polyethylene containers and covered with enough local water to retard drying until such time as these materials could be analyzed. The fine materials which had passed through the 60 μ sieve (mesh 250) do not lend themselves readily to size analysis by sieves; thus, a sedimentation process based upon a consideration of terminal velocities was used for these. Terminal velocities were determined for the fine particles by using a simplification of Stokes' equation together with related

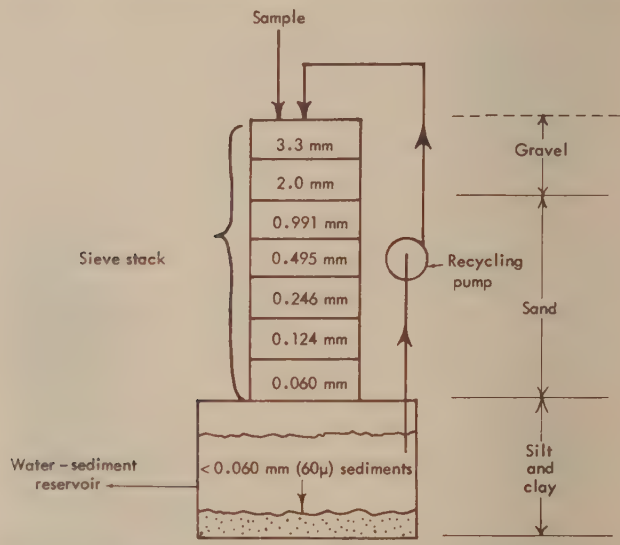


Figure 6.-Sketch of Wet Sieve Equipment and its Operation

correction factors. The assumptions used to simplify Stokes' equation are as follows:

1. Sediment particles were assumed to be spherical.

2. Specific gravity of the brackish dispersion water was assumed equal to that of fresh water.

3. Specific gravity of 2.7 was assumed for the mud sample.

Table 1.-Particle Size Designation and Sieve Size (8)

| Wentworth Particle Size Designation | Sieve size openings | |
|---|---|---|
| | Millimeters | U.S. standard mesh |
| Pebbles | 3.962 | 5 |
| Granules | 3.327 | 6 |
| Very coarse sand | 1.981 | 9 |
| Coarse sand | 0.991 | 16 |
| Medium sand | 0.495 | 32 |
| Fine sand | 0.246 | 60 |
| Very find sand | 0.124 | 115 |
| Silt | 0.061 | 250 |

For a more accurate and precise determination of terminal velocities, the above three factors should be actually determined and not assumed; however, for the purposes of this study, the assumptions were quite adequate.

Two methods of size separation can be used in the sedimentation process. One, a static method, was used in this project; the other, a dynamic method, is conceptual only. The first step of the static method, shown schematically in figure 7, involved the thorough mixing of the sediment and then allowing the mixture to settle until most of the coarse material had settled from the mixture. The fines which had not settled were then siphoned from the upper portion of the suspension and were further separated by the technique illustrated in figure 7. The coarse material which had settled was reclaimed for the second step. The settling time for the fractions being separated was based upon their calculated terminal velocities (see table 2).

Table 2.-Terminal Velocities for Spherical Particles (Assumed Specific Gravity of 2.7) in Pure Water at 20° C (7)

| Wentworth Particle Size Designation | Particle size (millimeters) | Terminal velocity | | Time to settle 5 cm |
|---|---|---|---|---|
| | | ft/sec | cm/sec | |
| Fine sand | | | | |
| | 0.124 | $3.8 \times 10^{-2}$ | 1.16 | 4.3 sec |
| Very fine sand | | | | |
| | 0.060 | $1.1 \times 10^{-2}$ | 0.335 | 14.9 sec |
| | 0.030 | $2.8 \times 10^{-3}$ | 0.0853 | 58.6 sec |
| Silt | 0.015 | $7.2 \times 10^{-4}$ | 0.0219 | 3 min 48 sec |
| | 0.0075 | $1.4 \times 10^{-4}$ | 0.00427 | 19 min 23 sec |
| | 0.0039 | $4.5 \times 10^{-5}$ | 0.00137 | 60 min 49 sec |
| Clay | | | | |

In the second step, the remaining coarse material was mixed and allowed to settle for a shorter time as determined by the terminal velocity of the next larger size fraction, as shown in table 2. Again the top material was siphoned off. This latter separation produced fines which in themselves had to be separated by using the first step of the sedimentation technique as already outlined.

The dynamic procedure is being developed because the wet sieving process proved to be cumbersome and inadequate for the separation of particles equal to or less than 0.5 mm and somewhat cumbersome for the separation of the larger particles. The dynamic procedure, it is anticipated, will accomplish more

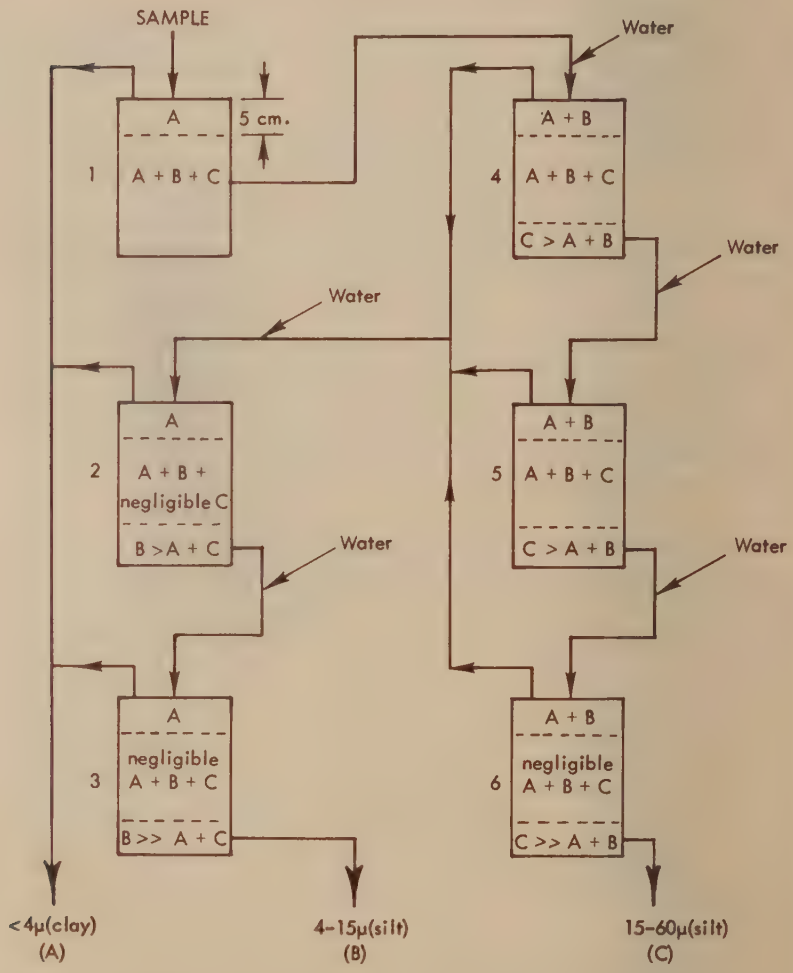


Figure 7.-Flow Sheet for the Static Method of Sediment Separation (Note: Operations 1, 2, and 3 each use a settling time of 1 hr. 49 sec.; operations 4, 5, and 6 each use a settling time of 3 min. 48 sec.)

effectively what the complete wet sieving and sedimentation process could accomplish only with difficulty. In the design of the equipment for the dynamic process, 5 elutriation columns are to be arranged in successive gradations, with the smallest diameter column being first and the largest one last. Figure 8 shows a schematization of the equipment and a flow diagram of how a sediment sample is to be ideally separated by this process.

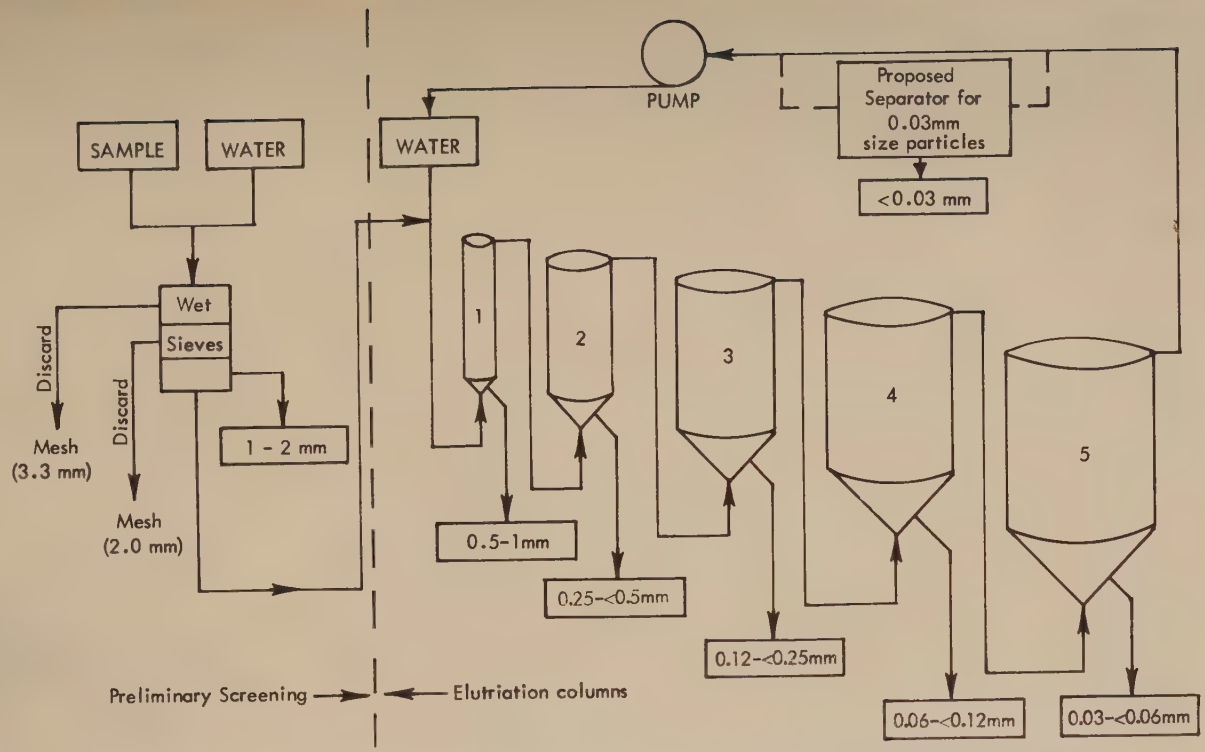


Figure 8.-Flow Sheet for Size Separation of Bottom Sediments Using Elutriation Columns

The mud sample, containing particles no larger than the 1 mm size after preliminary screening, will flow with its local water into the bottom of the first cylinder. This flow rate has been so selected, and the diameter of the first cylinder so designed, that particles < 0.5 mm in size will be flushed up through the first cylinder and introduced into the bottom of the next larger cylinder. The particles remaining in the first cylinder will be collected at the end of the process and will constitute the $\leqq$ 1.0 to $\geqq$ 0.5 mm-size sample. The second cylinder is also of such a diameter that for the chosen flow rate, particles < 0.25 mm will flush over the top and into the third cylinder. Particles in the size range < 0.5 to $\geqq$ 0.25 mm will remain in the second cylinder and so constitute the sample for this size fraction. The procedure will continue through the remaining three cylinders of progressively larger diameters, with a particular sized sample remaining within each cylinder for removal at the end of the process. The largest cylinder will retain the particles 0.03 to 0.06 mm in diameter. The 0.03 mm-size particle is about the smallest particle that can be practically separated by using the dynamic elutriation column. At present no workable method has been developed that will remove the < 0.03 mm-size particles from the recycled stream at the designed flow rate. Thus, with the continuous recycling, there will be some contamination of each separated fraction by the < 0.03 mm-size material. This contamination should present no problems because a large amount of local water is to be used; thus, the < 0.03 mm-size material will be well dispersed. As soon as the elutriation columns are constructed and tried, efforts will be directed toward the designing of a practicable method for removing the < 0.03 mm-size material from the flow stream.

## Data Analysis

To date, only 3 months' analytical results have been produced from the estuarial survey. As more results become available, it is hoped that an evaluation of geographical effects can be made from an examination of these data. Also, it is desired to compare in due time the concentrations of radioactivity measured at each station so as to determine seasonal cycles which may exist. Refinements or changes of sampling methods, of sample analyses, and of any other aspect of the survey will be made as indicated by valid interpretations of all the survey data.

Radiological data which have been derived from the estuarial study are represented by the bar graphs shown in figure

3. The stations designated on each of the graphs are arranged from left to right to follow closely the actual downstream sequence. There appears to be a trend of decreasing activity in a downstream direction; however, this trend is so slight that its significance is questionable.

One desired result of the SEERS Project is to collect and tabulate the radiological data of the Savannah Estuary in such a form that they can easily be compared with similar data from other areas. The Savannah data have been recorded on cards which are filed by project code and by the type of sample analyzed. These cards contain the following information: location, sampling station, fraction of sample, type of sample, sample number, date of collection, laboratory sample number, date of analysis, $\alpha$, $\beta$, and $\gamma$ activities. This method of data handling became rather unwieldly after the accumulation of a number of sample results; thus a change was made to cards of the Keysort System. These Keysort cards have the same data typed on them, as well as the location, sampling station, fraction of sample, type of sample, and sample number coded and punched in the fields located around the edges of the cards. With this system the cards need not be filed in categories, for the desired information can be easily found by use of the code and the perforated fields along the sides of the cards. This method has an increased capacity over the former card filing system; however, even the Keysort System becomes cumbersome when the number of results exceeds 1,000. With this limitation in mind, it was decided that the final system should employ high speed punched cards and computer equipment.

The use of a computer is greatly simplified if all data are supplied in a standard form. To facilitate this, a source document was designed for use in the total flow of data from field sampling to computer programming. This source document has undergone several revisions and no doubt will be revised many more times before the final form is acceptable for all phases of data flow. The present form of the source document is shown in figures 9 and 10. The coding has been worked out by Mr. Paul D. Eckrich and others and is available at Technical Operations Branch, Division of Radiological Health, Radiological Health Laboratory, Rockville, Maryland. It should be mentioned that this coding, together with the source document, has been developed for all types of environmental sampling and not just estuarial sampling. Thus, by using such a source document, almost all environmental data can be analyzed by automatic data processing equipment.

ENVIRONMENTAL RADIATION SURVEILLANCE REPORT

FIELD DATA

CARD #1 1. Sample Number 1 2 3 4 5 6

2. Type of Sample 7 8 9

3. Fraction of Sample 10 11

4. Card Identification (do not use) 12 13

5. Location _____ 14 15 16

Station _____ Substation _____ 17 18 19 20

6. State _____ County _____ 21 22 23 24 25

City _____ 26 27 28

7. Date Sampled 29 30 31 32

| | | | |
|---|---|---|---|
| Weight of container and sample | | Weight of container and sample and preservative | |
| Weight of container | | Weight of container and sample | |
| Weight of sample | | Weight of preservative | |

LABORATORY DATA

8. % ash _____ 33 34 35 36

% moisture _____ 37 38 39 40

weight ash _____

method of ashing used _____ 41 42 43 44 45

9. Number of analyses made on this sample 46 47

10. Type of analysis _____ 48 49 50 51 52

1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
9. Other (specify)

53 54 55 56 57

58 59 60 61 62

_____ ± _____
(circle correct units)

11. Type of analysis _____ 63 64 65 66 67

1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
9. Other (specify)

68 69 70 71 72

73 74 75 76 77

_____ + - _____
(circle correct units)

Department of Health, Education & Welfare, PHS, Div. of Rad. Health

12. Project Identification E 79 S 80

Figure 9.-Sample Form for the First Page of a Typical Source Document

ENVIRONMENTAL RADIATION SURVEILLANCE REPORT

CARD # ____ SAMPLE NUMBER 1 2 3 4 5 6 7 8 9 10 11 12 13

LABORATORY DATA

ITEM # ____
Type of Analysis _____ 14 15 16 17 18
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 19 20 21 22 23
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
_____ ± _____ (circle correct units) 9. Other (specify) 24 25 26 27 28

ITEM # ____
Type of analysis _____ 29 30 31 32 33
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 34 35 36 37 38
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
_____ ± _____ (circle correct units) 9. Other (specify) 39 40 41 42 43

ITEM # ____
Type of Analysis _____ 44 45 46 47 48
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 49 50 51 52 53
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
_____ ± _____ (circle correct units) 9. Other (specify) 54 55 56 57 58

ITEM # ____
Type of Analysis _____ 59 60 61 62 63
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 64 65 66 67 68
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
_____ ± _____ (circle correct units) 9. Other (specify) 69 70 71 72 73

REMARKS: (refer to item number)

Department of Health, Education & Welfare, PHS, Division of Radiological Health

6. Project Identification E S 79 80

Figure 10.-Sample Form for the Second and Succeeding Pages of the Typical Source Document

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# LARGE LOOKDOWNS FROM TAMPA BAY, FLORIDA

Carl H. Saloman and Gordon R. Rinckey

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# LARGE LOOKDOWNS FROM TAMPA BAY, FLORIDA

Carl H. Saloman and Gordon R. Rinckey

During a recent cold spell (December 12-13, 1962), 17 large lookdowns, *Selene vomer* (Linnaeus), were found dead on the beaches or in a stunned condition in the water north of Pass-a-Grille channel. The water temperature at that time was 10.4° C. and salinity 33.0 o/oo, in contrast with readings for the previous week (December 3) of 18.1° C. and 32.4 o/oo.

Thirteen females and four males were in the group recovered. The largest specimen, a female, measured 287 mm., S. L. (standard length) and 375 mm., T. L. (total length). The body depth was 68.6 per cent of the length (S. L.). The fin ray counts of this specimen were as follows: dorsal (22), anal (18), and pectoral (18). The size ranges for females and males in the sample were: 163 to 387 mm. and 163 to 200 mm., S. L., respectively. The corresponding mean lengths for the sexes were 202.54 mm. and 180.00 mm., S. L.

During 18 months of regular sampling in Tampa Bay, 3 small specimens of *S. vomer* were collected. Two were caught in June, 1962 (39.0 and 43.0 mm., S. L.), and one in August, 1962 (28.0 mm., S. L.).

Several large specimens of this species have been reported, but none larger from the west coast of Florida. Reid (1954) reported one specimen 33 mm. in length, taken near Seahorse Island, Florida. Joseph and Yerger (1956) reported no adult specimens from Alligator Harbor, but one adult, 216 mm. S. L., from Gulf Beach, one mile west of Bald Point, Florida. Springer and Woodburn (1960) reported one specimen 17.9 mm. S. L., from Belle Vista Beach, Florida. Tabb and Manning (1961) collected *S. vomer* twice from Sandy Key Basin and East Cape Sable in northern Florida Bay, but gave no measurements of the specimens.

Large specimens of *S. vomer* taken elsewhere in the Gulf have been reported by various authors. The largest to date is one 483 mm. T. L., (360 mm. S. L.) taken at Port Aransas, Texas (Pounds, 1962). Ginsburg (1952) reported a specimen 317 mm. long, from Jamaica and another 195 mm. long, from the Gulf of Mexico. Gunter (1945) reported a specimen 123 mm. long from Texas. Hildebrand (1939) mentions one *S. vomer* of 320 mm. S. L. from Gatun

Locks, Panama. Hildebrand (1954) reported specimens ranging from 72 mm. to 111 mm. in length, in the western Gulf.

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*Biological Station, U. S. Bureau of Commercial Fisheries, St. Petersburg Beach 6, Florida.*

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# A Study of the Quality of Sea Water Temperatures Reported in Logs of Ships' Weather Observations

J. F. T. SAUR

*U. S. Bureau of Commercial Fisheries Biological Laboratory, Stanford, Calif.*

(Manuscript received 27 August 1962, in revised form 14 January 1963)

ABSTRACT

The differences between sea water temperature reported in the Log of Ship's Weather Observations and specially observed sea surface temperature were studied for 6826 pairs of observations taken in the Pacific Ocean from 3 Military Sea Transport Service ships and 9 U. S. Navy Radar Picket ships during 92 different trips. For each trip the mean difference (*trip* bias), using the surface temperature observations for the reference, and the standard deviation of the differences were computed. These results were combined to give similar measures for each ship (*ship* bias and standard deviation) and estimates of these measures for a large number of ships (*fleet*).

Reported sea water (injection) temperature observations vary considerably in quality. The *fleet* bias, or mean difference, of injection temperature observations as compared to surface temperature observations is estimated to be 1.2±0.6F and the standard deviation of differences to be 1.6F. Among the 12 ships, the *ship* bias, or mean of all differences derived from observations of a given ship, ranged from −0.5F to 3.0F, which is probably due to variations of the thermometer accuracy and of the thermometer installations between ships. The standard deviation about these means was 1.3F, which is a measure of the variability of present data records, *provided* that the bias for each ship could be determined and a correction applied.

The variability of differences in the observations from a single ship is attributed to the system of taking and reporting sea water temperature observations from an injection thermometer. To improve the reliability of reported sea water temperature observations, a change to an electrical resistance or thermistor thermometer, specially designed and installed to measure the sea water temperature and having a remote indicator on the ship's bridge, is recommended. If this change were made, it is estimated from trip data that the standard deviation of differences would be reduced to less than 1.0F.

## 1. Introduction

Historically, observations of sea water temperature have been taken and recorded as a part of marine weather observations. For U. S. ships, a fraction of the weather observations are reported by radio, collected, disseminated by teletype, and used for synoptic forecasting. Many more are recorded on log sheets (Log of Ship's Weather Observations, Weather Bureau Form 615-5, formerly 1210F) which are collected by the Marine Centers, U. S. Weather Bureau, and are deposited at the National Weather Records Center.

The sea water temperature observations have been little utilized in the past except for climatological studies, such as for the *Atlas of Climatic Charts of the Ocean* (U. S. Weather Bureau, 1938), *World Atlas of Sea Surface Temperatures* (Hydrographic Office, 1944), and more recently the *Marine Climatic Atlas of the World, Vols. I and II* (Chief of Naval Operations; 1955, 1956). Now, however, descriptions of oceanic phenomena with greater resolution in time as well as space are needed. For example, Namias (1959) has shown how variations in feedback of energy from the ocean to the atmosphere—dependent upon ocean temperatures—may play an important role in long-period variations of prevailing wind circulations. Also, month-by-month charts of sea surface temperature in the North Pacific Ocean are being compiled from these observations by the Bureau of Commerical Fisheries Biological Laboratory, Stanford (1962), for the purpose of studying the effects of environmental variations on abundance and availability of commercial fishes.

Reported sea water temperature observations are known to be of uncertain accuracy, however. The sea water temperatures on ships of U. S. registry are generally read from a thermometer in the engine room mounted at some location in the sea water injection system of the ship and are commonly called "injection temperatures." The effect of heating within the system, the procedures for taking and reporting the observation, observational error, inaccuracy of the thermometer, and real differences between the sea temperature at the intake level and the sea surface, all contribute to differences and variability in readings between injection and surface temperatures.

Oceanographers often state that the injection temperatures on the average are about 1F higher than surface bucket temperatures. This belief probably arose from studies of temperatures taken with bathythermo-

gram observations during World War II, but no documentation seems to be readily available. In describing the preparation of charts of Air-Sea Temperature Difference, the *Marine Climatic Atlas of the World, Vol. I* (Chief of Naval Operations, 1955) states, "Due principally to the extremely variable and often unreliable quality of ships' sea temperature observations, these charts are seasonal and contain isopleths only." When one considers that a temperature decrease of 1C in only 1 meter of water can release enough heat to increase the temperature almost 4C in the lower 1000 meters of the atmosphere, observations of sea water temperature should certainly be made with comparable or, preferably, higher accuracy than those of air temperature.

Franceschini (1955) compared the temperature distribution of the surface water in the Gulf of Mexico as determined by certain short-period averages of commercial vessel reports to the distributons as determined from three oceanographic surveys made in 1951 and 1952. Using this indirect method, he concluded that in the Gulf of Mexico short-period averages of ship reports could be used for practical purposes, e.g., forecasting air mass modification. However, he found it necessary to determine and apply corrections—some as large as 5F—to the reports from commercial vessels, when there were fewer than 10 reports per quadrangle for which the average temperature was computed. His success was probably due, therefore, to a fairly high density of observations and relatively uniform temperature conditions throughout much of the Gulf of Mexico.

At our laboratory, for the construction and use of the monthly charts of sea surface temperature in the North Pacific Ocean, a measure of the reliability of the observations was needed. The uncertainty regarding accuracy of historical data made it desirable to obtain some direct measurements of the difference between reported sea water temperatures and sea surface temperatures. This information would further assist in establishing a course of action with regard to future observations.

Through the cooperation of U. S. Weather Bureau observers aboard Military Sea Transport Service ships operating in the Pacific Ocean and U. S. Navy personnel aboard radar picket ships operating off the west coast of the United States, such direct measurements have been obtained during a $2\frac{1}{2}$-yr period. An analysis of the differences between paired observations of sea surface temperature, as taken by a bucket thermometer, and of sea water temperature, as reported in the weather log from injection measurements, is given here.

## 2. Observational program

For the period May 1959 through May 1960, data (given in Table 1) were obtained from three transports of the Military Sea Transport Service (hereafter referred to as MSTS). These MSTS ships operated on trans-Pacific routes from San Francisco, and occasionally from other west coast ports, to Japan and/or western Pacific bases of the United States, such as Okinawa, Manila and Guam. Occasionally stops were made at Honolulu.

For the period September 1960 through January 1962, data were obtained from nine U. S. Navy radar picket ships (Table 1). Seven were liberty ships converted for radar picket duty (AGR class) and two were destroyer escorts (DER class). Data were obtained from each ship for about one year. These radar picket ships operated out of San Francisco to five stations located about 300 mile off the west coast of the United States, maintained positions within a 50-mile-diameter circle for a period of 21 to 30 days, and returned to port. Station assignment was rotated, but the range of temperature encountered on any given trip was small compared to that for a trip by an MSTS vessel.

TABLE 1. Ships participating in program of surface temperature observations.

| |
|---|
| Military Sea Transport Service |
| USNS General H. J. Gaffey |
| USNS General E. D. Patrick |
| USNS General D. I. Sultan |
| Radar Picket Ships |
| USS Interceptor (AGR 8) |
| USS Interdictor (AGR 13) |
| USS Interpreter (AGR 14) |
| USS Locator (AGR 6) |
| USS Picket (AGR 7) |
| USS Scanner (AGR 5) |
| USS Tracer (AGR 15) |
| USS Koiner (DER 331) |
| USS Lowe (DER 325) |

*Sea surface temperature.* Special thermometers and thermometer holders were furnished to each ship for making the observations of sea surface temperature. The holder, or "bucket," was designed at Scripps Institution of Oceanography specifically for taking sea surface temperature observations. An inner plastic cup holds a water sample around the thermometer bulb. This is separated by an air space from an outer metal case which protects the plastic cup from damage and acts as a shield against radiation and evaporation while the temperature is being read. The thermometers were graduated in 0.2F and could be read easily to the nearest 0.1F. Each thermometer was checked in the laboratory to assure an accuracy of $\pm 0.15$F and most were found to be accurate to $\pm 0.10$F or better. Except for infrequent gross reading errors, such as an error of 10F, it is estimated that the probable error ($0.6745\sigma$) of observation would be about 0.1F.

Aboard the MSTS ships the special observations were made twice daily, workload permitting, by the Marine Observers of the U. S. Weather Bureau, Marine Center, San Francisco, with the 0600 and 1800 GMT weather observations. From the radar picket ships, four observations a day were taken by the aerological personnel at 0000, 0600, 1200 and 1800 GMT.

*Sea water temperature.* An attempt was made to insure that the sea water temperatures obtained for the comparative analysis were as representative as possible of those routinely reported. In enlisting the cooperation of ships' weather personnel for obtaining the special surface temperature observations, care was taken not to alter the usual routine of the ship for obtaining the sea water temperature for entering in the Log of Ship's Weather observations.

The instrument used for these observations is generally a standard industrial hot water (sometimes called "hot well") thermometer, which is a mercury-in-glass thermometer whose bulb is protected by a thin metal case. This bulb is further seated in a second metal case or "well," which is semipermanently installed in the pipe. It protects the thermometer from the water and pressure and permits the removal and exchange of thermometers without shutting down and draining the injection system. The thermometers, although used for measuring the sea water temperature, have ranges as great as 30F to 180F and 30F to 240F and are graduated in 2F or sometimes 5F intervals. The sea water temperatures are reported in whole degrees Fahrenheit.

The size of the pipe, location and depth of intake, location of overboard discharge, location of thermometer, etc., vary greatly among classes of ships, and some minor differences may exist between installations on ships of the same class. In addition to a main injection system, there are other sea water lines for auxiliary equipment on which thermometers are also mounted. As a further complication, many ships have more than one engine room.

On the ships participating in this program, the depth of the sea water intake ranged from 10 to 22 feet below the surface and the inner diameters of the pipes from 4 to 20 inches. The thermometers were located along the injection lines from within a few feet of the hull to as much as 25 feet inboard at the entrance of the line to the condenser jacket.

An "oiler" maintains a rough log hourly of the readings from the various thermometers and gauges in the engine room. The smooth engine room log is prepared just prior to the end of each 4-hour watch. There seems to be no standard procedure among ships as to which reading of sea water temperature is given to the weather personnel or bridge. The sea water temperature data used in this analysis were taken from the weather logs.

### 3. Analysis of data

Prior to the statistical analyses, gross errors appearing on the data sheets in both the surface temperature observations and the injection temperature observations were eliminated by inspection. During this process, frequent large and variable differences were noted between paired observations taken by MSTS ships in the Yellow Sea and very close to the south coasts of the Japanese islands of Kyoshu and Shikoku. It appeared that these were due to large natural variations and were not typical of observations from the open ocean, so all observations from these regions were eliminated.

Table 2 gives for each ship the total number of observational pairs of injection and sea surface tempera-

TABLE 2. Observational pairs of injection temperature and sea surface temperature by ship.

| Ships | Number of trips | Total observations | Observations per trip: Minimum | Observations per trip: Maximum |
|---|---|---|---|---|
| Military Sea Transport Service | | | | |
| MSTS—A | 11 | 445 | 14 | 52 |
| MSTS—B | 9 | 412 | 31 | 59 |
| MSTS—C | 7 | 326 | 19 | 62 |
| Radar Picket Ships | | | | |
| AGR—D | 7 | 783 | 105 | 116 |
| AGR—E | 6 | 582 | 61 | 132 |
| AGR—F | 9 | 882 | 78 | 130 |
| AGR—G | 5 | 370 | 53 | 90 |
| AGR—H | 6 | 592 | 87 | 113 |
| AGR—J | 7 | 669 | 69 | 114 |
| AGR—K | 8 | 697 | 60 | 113 |
| DER—L | 8 | 399 | 20 | 76 |
| DER—M | 9 | 669 | 68 | 83 |
| Total | 92 | 6826 | | |

tures used in this analysis, the number of sets of observations for each ship and the minimum and maximum of observations per set (trip). Since it is not the intention to indicate here that a certain ship may report more or less reliable temperatures than others, ships are henceforth identified only with a prefix for the type of ship followed by a letter.

In this study, the difference, $\delta$, between the reported sea water (injection) temperature, $T_I$, and the surface (bucket) temperature, $T_S$, defined by

$$\delta = T_I - T_S, \tag{1}$$

is being examined. Two statistics are employed: a) the bias of the injection temperature (mean difference), $\bar{\delta}$, defined by

$$\bar{\delta} = \frac{1}{N}\sum_{j=1}^{N}(T_I - T_s)_j = \frac{1}{N}\sum_{j=1}^{N}\delta_j, \tag{2}$$

where $N$ is the number of observational pairs; and b) the standard deviation of the differences, $s_\delta$, defined by

$$s_\delta = \left[\sum_{j=1}^{N}\frac{(\delta_j - \bar{\delta})^2}{N-1}\right]^{\frac{1}{2}}. \tag{3}$$

The bucket temperature is used as a reference under the assumption that errors in these temperatures are small and contribute little to the variance of the difference between injection and bucket temperature.

Three different ways of grouping the observational data were employed. Distinction is made by designating the statistics determined from the observations of a single trip of a given ship as the *trip* bias and the *trip* standard deviation. Statistics based upon all the observations from a given ship are termed the *ship* bias and *ship* standard deviation. When all observations from all ships are grouped together, the statistics are called the *fleet* bias and *fleet* standard deviation.

Caution is required if the latter statistics are to be applied to any particular set of observations taken from the files at the National Weather Records Center, where those in Deck 116, for example, are from many types of ships, with merchant vessesl predominating. The statistics in this study are based upon a sampling of only 12 ships and, particularly, only 3 different classes of ships, none of which were merchant ships.

## 4. Results

*Trip bias and standard deviation.* A typical distribution of the differences, $\delta$, from one trip of an MSTS ship is shown in Fig. 1. The *trip* bias is 1.5F and the *trip* standard deviation is 1.3F. Regression analyses were made on trip data to determine whether or not the differences were a function of temperature, but no such dependence was found.

Table 3 shows the manner in which the *trip* bias and *trip* standard deviation may vary between different trips of the same ship. For this particular ship, AGR-K, the *trip* bias varied from 0.3F to 1.8F and the *trip* standard deviation varied from 0.5F to 1.3F. The variability from trip to trip is characteristic of almost every ship, as seen in Fig. 2 and Fig. 3, which show for each ship the distributions of the *trip* biases and the distributions of the *trip* standard deviations, respectively.

TABLE 3. Trip bias, $\delta$, and trip standard deviation, $s_\delta$, for each trip of radar picket ship AGR-K.

| Month | Year | No. of obs. | $\delta$ (F) | $s_\delta$ (F) |
|---|---|---|---|---|
| Aug.–Sep. | 1960 | 89 | 1.8 | 0.7 |
| Sep.–Oct. | 1960 | 93 | 1.3 | 1.3 |
| Jan. | 1961 | 60 | 0.5 | 0.5 |
| Mar. | 1961 | 85 | 1.7 | 0.9 |
| Apr.–May | 1961 | 113 | 1.8 | 1.1 |
| Jun.–Jul. | 1961 | 105 | 0.9 | 1.0 |
| Aug.–Sep. | 1961 | 75 | 0.3 | 0.7 |
| Sep.–Oct. | 1961 | 77 | 1.3 | 0.8 |

*Ship bias and standard deviation.* All temperature differences observed from a single ship are used to compute the *ship* bias and *ship* standard deviation, which are shown in Table 4 for each ship, along with the value of the *pooled trip* standard deviation. In this sample of 12 ships the *ship* bias ranged from −0.5F to 3.0F. The *ship* standard deviations range from 0.9F to 1.9F. The amount by which the *ship* standard deviation exceeds the *pooled trip* standard deviation depends upon the inconsistency of the *trip* biases for that ship.

TABLE 4. Ship bias, $\bar{\delta}$, ship standard deviation, $s_\delta$, and pooled trip standard deviation, $\langle s_\delta \rangle$, for each ship.

| Ship | No. of obs. | $\bar{\delta}$ (F) | $s_\delta$ (F) | $\langle s_\delta \rangle$ (F) |
|---|---|---|---|---|
| MSTS—A | 445 | 1.2 | 1.5 | 1.3 |
| MSTS—B | 412 | 1.3 | 1.1 | 1.0 |
| MSTS—C | 326 | −0.5 | 1.1 | 1.1 |
| AGR—D | 783 | 1.5 | 1.0 | 0.9 |
| AGR—E | 582 | 1.1 | 1.0 | 1.0 |
| AGR—F | 882 | 2.2 | 0.9 | 0.7 |
| AGR—G | 370 | 3.0 | 1.8 | 1.0 |
| AGR—H | 592 | 1.1 | 1.4 | 0.9 |
| AGR—J | 669 | 1.5 | 1.9 | 1.1 |
| AGR—K | 697 | 1.3 | 1.1 | 0.9 |
| DER—L | 399 | 0.1 | 1.2 | 1.0 |
| DER—M | 669 | 0.1 | 0.9 | 0.8 |

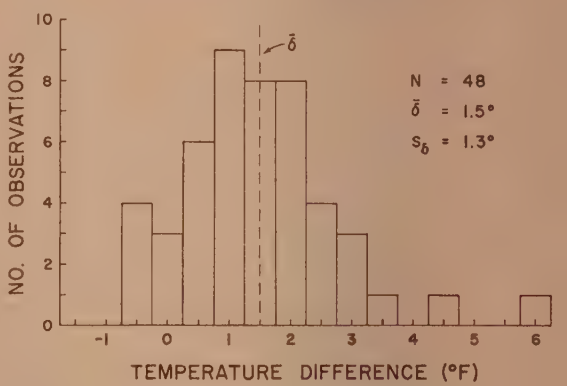


FIG. 1. Distribution of temperature differences, $\delta$, for one trip of an MSTS ship, June–July 1959.

*Fleet bias and standard deviation.* These measures were computed using the data from all ships, except that the computations were adjusted to give equal weight to the results from each ship regardless of the differing number of observations. The *fleet* bias from these 12 ships was found to be 1.2F and the *fleet* standard deviation to be 1.6F. For the 12 ships the *pooled ship* standard deviation is 1.3F and the *pooled trip* standard deviation is 1.0F.

## 5. Discussion

The 95 per cent confidence limits for the *fleet* bias were found to be 1.2±0.6F. On the assumption that the 12 ships sampled are not greatly atypical, one may conclude that injection temperatures reported in logs of ships' weather observations probably have, on the average, a real positive bias as compared to surface temperature. The results support the belief that injection temperatures exceed surface temperatures by about 1F. This bias is opposite in algebraic sign to that which might be expected from the occurrence of vertical temperature

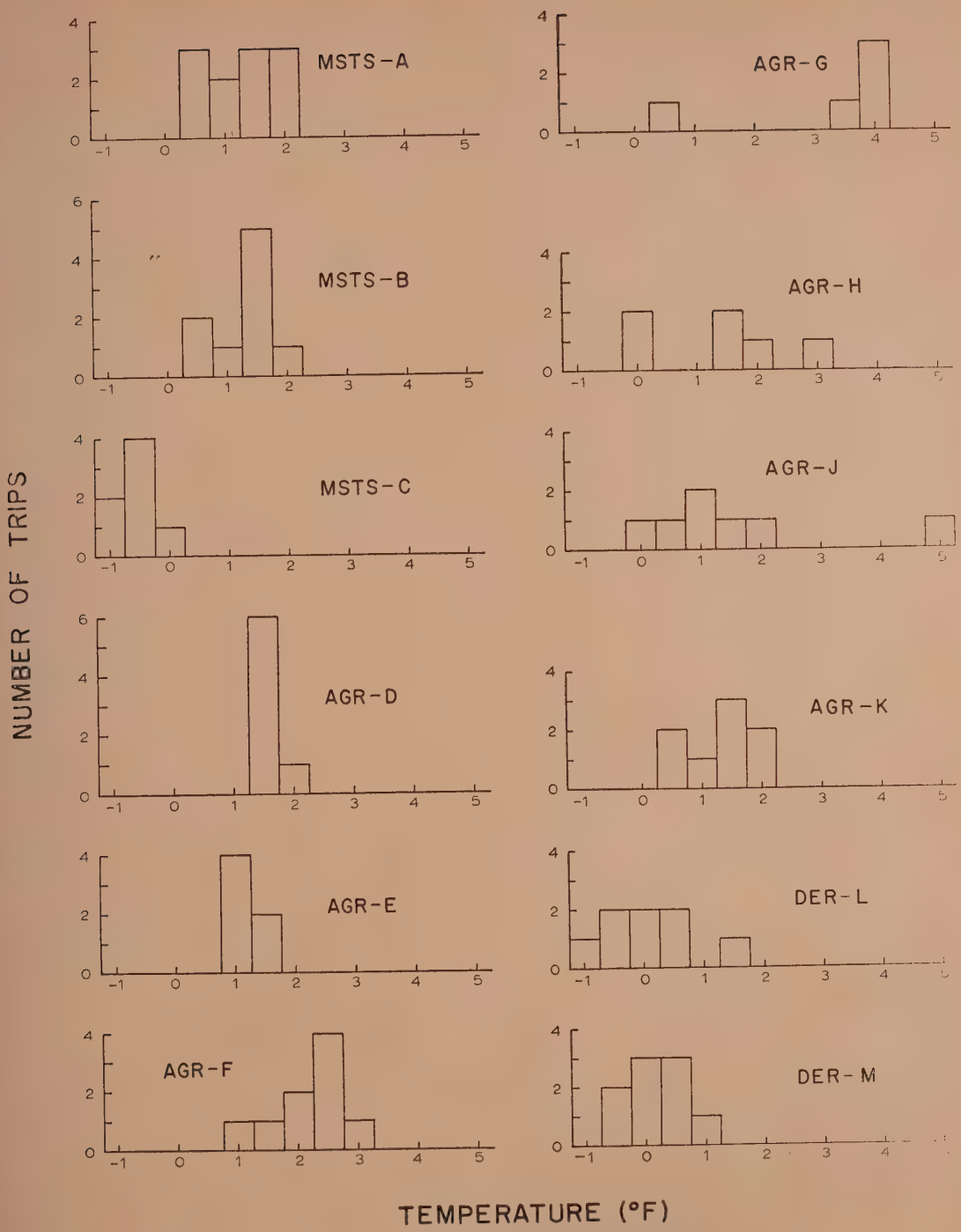


Fig. 2. Distributions of *trip* bias for each ship.

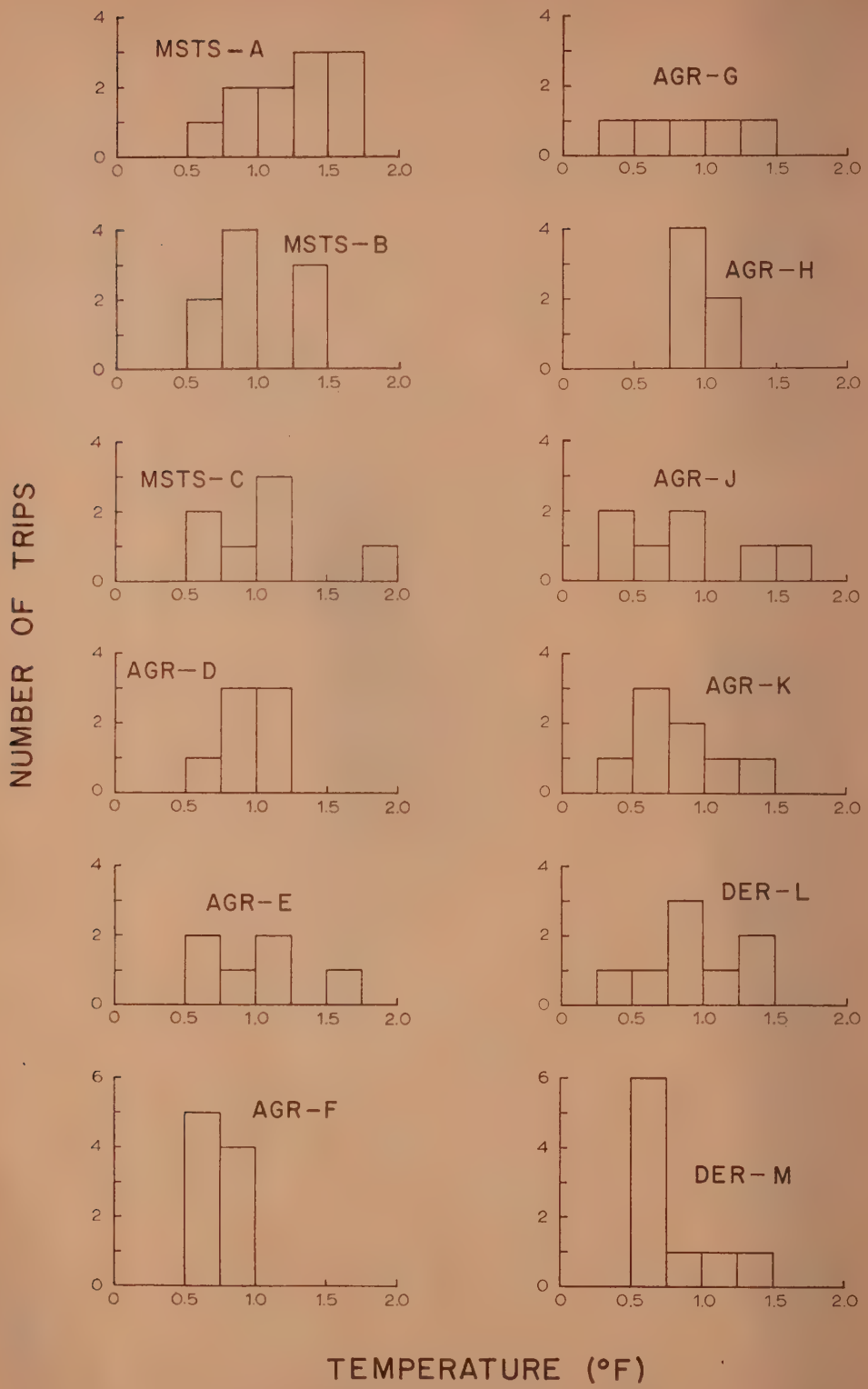


FIG. 3. Distributions of *trip* standard deviation for each ship.

gradients between the surface and depth of sea water intake.

The main purpose of this program was to obtain information on the quality of data reported in the routine manner. It was felt that placing an independent observer aboard the ships in an attempt to determine the causes of the differences would have defeated this purpose. My first subjective opinion would attribute the bias to the temperature of the water in the pipe probably being raised by the heat of the engine room prior to reaching the thermometer. However, as a result of visits to the ships, my second impression is that, because of incrustation or fouling, poor exposure of the well to the flow on some ships and possible air space inside the well, heat conduction along the metal fittings to the thermometer bulb may have a greater effect in causing bias than warming of the water.

The between-ship variance of bias, i.e., the inconsistency of *ship* bias, could well be caused by the variations from ship to ship in the conditions cited in the above paragraph. Thermometer errors must also be included as a cause of between-ship variance of bias.

Some special observations made aboard five U. S. Coast Guard Weather Ships[1] have demonstrated some of the problems encountered with injection temperatures. The injection thermometers were demounted and checked at several temperatures against an accurate standard thermometer. Temperature errors from the five thermometers ranged from −2.0F to 3.9F. Results of other observations indicated that the differences between injection temperature corrected for thermometer error and surface temperature "varied erratically both among ships and on individual ships at different speeds."

In the analyses of existing sea water temperature observations in which the ship is identified, it may sometimes be possible to determine the *ship* bias relative to many other ships by a procedure which evaluates internal consistency of the data, and to apply a constant correction to all of the observations from the particular ship. The estimated reliability of the data to be expected after applying this "calibration" procedure is indicated by the *pooled ship* standard deviation of 1.3F. This is probably the best that one can do to improve the quality of existing sea temperature records and those that continue to be read from present thermometers in injection systems.

It is believed that a major portion of the variability represented by the *ship* standard deviation stems from a lack of specific instrumentation aboard the ships for the purpose of making sea water temperature observations. For example, due to the lack of rigid procedures, there may be an appreciable and variable lag from the time of taking a thermometer reading in the engine room to the time for which it is logged in the weather report. Due to the movement of the ship, the observation would thus have an incorrect position.

The data from the three MSTS ships were examined for this "lag" effect by selecting all the differences for which the absolute change in surface temperature during the preceding 12 hours, $\Delta T_{12}$, was 1.4F or greater. At normal speed a ship would move about 200 miles during a 12-hour period. The differences were separated into two groups, according to whether the ship was moving into warmer water or into colder water. The distributions of the differences for one ship, MSTS-C, show definitely, Fig. 4, that when the ship is traveling from warm to cold water ($\Delta T_{12}$ negative) the bias of injection temperature was 1.7F higher than when the ship was traveling from cold to warm water ($\Delta T_{12}$ positive). This difference between the two means is significant beyond the $P=0.001$ level. For the other two MSTS ships, the shifts in the means were 0.7F and 0.3F, which are significant at the $P=0.02$ and 0.07 level, respectively.

These results indicate that the injection temperature

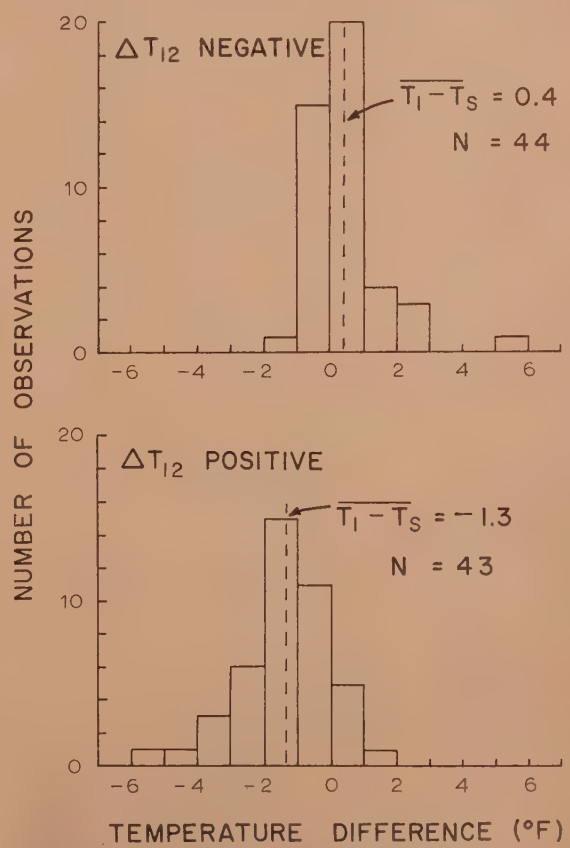


FIG. 4. Shift in distribution of differences between reported sea water temperature and surface temperature, when surface temperature has changed ($\Delta T_{12}$) more than 1.4F from the preceding 12-hr observation; ship MSTS-C.

[1] Robinson, Margaret K., 1962: Report to the Eastern Pacific Oceanic Conference on comparisons of bucket and injection temperatures on Pacific Ocean weather stations. Unpublished manuscript presented to the Conference on October 3–5.

may be read sufficiently in advance of the time of the weather observation frequently enough to introduce a substantial error into the data when the ship is traveling through water of changing temperature. The few outlying large differences (Fig. 4) show that the error is sometimes very large.

*Need for new instrumentation.* The results of this investigation indicate that steps should be taken as soon as possible to provide special instrumentation aboard ships for the specific purpose of obtaining reliable measurements of sea water temperature. In the preparation of specifications for such equipment, there are two primary considerations:

a) The sensing element should be located so as to measure correctly the temperature of the sea water, and
b) A remote indicating or recording device should be located where the logs of the weather observations are prepared.

An instrument utilizing an electrical resistance or thermistor element mounted on the outside of the hull, forward near the keel, and no more than a few meters below the water line, is recommended as one possible solution. A more complex system to avoid possible complications of biological fouling of the element would involve a water scoop with a short run of piping and shut-off valves inside the hull of a cool forward compartment, so that the element could be removed for cleaning. Either of these would have the advantage of removing the element from the influence of the injection system and could also be located so as not to be influenced by any overboard discharges. Another consideration is that such instrumentation could be installed at a standard depth below the surface on all ships, for example, at 3 meters.

A dial indicator, rather than a recorder, is recommended for installation at the weather station on all ships except oceanographic research ships. This would avoid a need of special attention by ships' personnel for the operation of the equipment.

A conservative estimate of the improvement in the data which might be expected from installing proper instrumentation aboard the ships can be seen by the decrease from the *ship* standard deviation to the *pooled trip* standard deviation for the same ship (Table 4, columns 4 and 5, respectively). As previously mentioned, the *pooled trip* standard deviation from these 12 ships is 1.0F. This statistic eliminates the effects of change in bias from one trip to another, but it still contains the effects of changes in procedures during a trip and of time lag between observation and recording in the weather log. For these reasons, it is believed that the standard deviation of data from ships using new instrumentation similar to that proposed would be reduced to less than 1.0F.

## 6. Conclusions

Sea water temperature observations read from sea water injection thermometers and reported as a part of the Ship's Weather Observations vary considerably in quality. The differences between paired sea surface temperatures and reported sea water temperatures are not consistent within the limits one might expect from the vertical gradients of temperature in the sea. The differences not only vary from ship to ship, but also exhibit a large degree of variability between trips of a given ship, or even during a trip. The data illustrate the conclusions of the World Meteorological Organization, Commission for Instruments and Methods of Observation (1957), that "intake measurements of water temperature suffer from lack of proper location of the thermometer, from unsatisfactory thermometers, and from crudeness of reading or timing."

The average bias of reported sea water temperatures as compared to sea surface temperatures, with 95 per cent confidence limits, is estimated to be $1.2 \pm 0.6$F on the basis of a sample of 12 ships. The standard deviation of differences is estimated to be 1.6F. Thus, without improved quality control, the sea temperature data reported currently and in the past are for the most part adequate only for general climatological studies.

The *ship* bias (average bias of injection temperatures from a given ship) ranged from $-0.5$F to 3.0F among the 12 ships. This inconsistency of bias between ships is probably due mainly to the differences in thermometers and their installations. If the *ship* biases can be determined and corrections applied to existing sea water temperature records, it is estimated that the standard deviation of differences would be reduced to 1.3F.

The relatively large variance of differences from a single ship is believed to result from the use of injection temperatures and the shipboard procedures for reading, communicating and eventual logging of the temperature. To improve the quality of the data it is recommented that new instrumentation, specially designed for taking sea temperatures, be installed aboard ships.[2]

The element should be free of the influences of the injection system, preferably be located at a standard depth on all ships, and have a remote indicator at the location aboard ship where the weather observation is logged. The data from this study indicate that with such instrumentation the standard deviation of differences between reported sea water temperatures and sea surface temperatures could be reduced to *less than* 1.0F.

[2] A personal communication from A. J. Lee, Fisheries Laboratory, Lowestoft, England, states that a thermistor thermometer has already been designed, successfully tested, and installed aboard English weather ships. Although the element was mounted in the sea water injection pipe, special tests were made to assure that on the test ship the temperature was not influenced by overboard discharges and was the same as that at the equivalent depth in the sea. The instrumentation is further being considered for installation on certain ships operating on regular schedules in the North Sea.

Placement of new instrumentation on existing merchant and naval ships would take a considerable period of time. In the interim period, observations taken by both types of instrumentation and procedures would be reported. Further, the Commission for Instruments and Methods of Observations, World Meteorological Organization (1957), has recommended "that bucket measurements (of sea temperature) be made in quiet, sunny weather at low latitudes." It would, therefore, seem appropriate that steps also be taken to have the method of observation reported along with the temperature and that this information be retained in data records.

*Acknowledgments.* Grateful acknowledgment is made of the cooperation of R. C. Nichols, Marine Supervisor, U. S. Weather Bureau, San Francisco, and CDR Donald C. Kirk, USN, Commodore, Radar Picket Suqadron ONE, which made possible the establishment of the observational program, and of the assistance of the Marine Observers, U. S. Weather Bureau, San Francisco and the Navy aerological personnel, who took the observations aboard the MSTS ships and the Navy radar picket ships, respectively. The supply of equipment to the ships and the liaison with the personnel regarding the methods of observation was done by David K. Justice. I wish to express my thanks to L. E. Eber and O. E. Sette for many helpful suggestions.

*Author's Note.* When originally preparing this manuscript I had overlooked an excellent early paper by C. F. Brooks [Observing Water Temperatures at Sea. *Mon. Wea. Rev.*, 54, June 1926, pp. 241–253]. His apparent objective of demonstrating the superiority of condenser intake temperatures to those observed using a canvas bucket and his statement in the synopsis, "A record from the condenser intake pipe appears truly representative of the surface temperatures under virtually all conditions," if taken out of context, tend to obscure the other valuable information he presents regarding sources of errors in condenser intake observations and in reported temperatures. For example, he mentions "lack of simultaneity" and presents data showing indirectly the increase in range of errors because of this, but dismisses the effect as "of little consequence in comparing averages." The article ends with a section, "The Case for Condenser Intake Thermographs." I can heartily recommend Brooks' paper, including the summary of the discussion of the oral presentation (American Meteorological Society, January 1925), and a written comment by F. G. Tingley, which follows, as informative and of historical interest.

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## *Elephant Seal in Puget Sound, Washington*

Motion pictures recently taken of a northern elephant seal, *Mirounga angustirostris*, represent the first record of this species for Washington. About 4:30 p.m. on 21 April 1963, Miss Laura Lenhardt and Mr. John O. Tennessen were fishing in Puget Sound about one-half mile west of Edmonds. As they cruised at 20 to 25 knots by outboard motorboat they saw the head and neck of a large seal with a fish in its mouth. They approached to within 35 feet, stopped, and took 8 mm color motion pictures with a 27 mm telephoto lens. The seal did not appear to be frightened. Its body, seen only through the water, was said to resemble a "tan log with white blotches, like barnacles." The fish was about "a foot and a half long, silver, like a 4- or 5-pound blackmouth salmon."

On 29 April we saw the pictures projected; they ran about two minutes. As the boat circled the seal, the back, sides, and front of the head and neck were revealed. The seal mouthed the fish before swallowing it, head first and whole. The seal was unquestionably a male adult elephant seal, as evidenced especially by the large, bulbous snout, rising at times above the level of the forehead. Both of us are familiar with the elephant seal of Mexican and Californian islands. The eyewitness description and the pictures tally in all respects with the known characters of this animal. — Victor B. Scheffer and Karl W. Kenyon, *U.S. Fish and Wildlife Service*, Seattle 15, Washington

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# Baculum Size in Pinnipeds

By Victor B. Scheffer and Karl W. Kenyon

*Eingang des Ms. 14. 6. 1962*

Baculum size in 20 species of pinnipeds (Order Pinnipedia) is shown in tables 1 and 2. Of the 20 genera of living pinnipeds, all but two *(Otaria* and *Ommatophoca)* are represented here. The tables are designed to show the zoological significance of the ratio: baculum size/body size in certain carnivores which have adopted diverse reproductive habits in the sea. Baculum weight and length are recorded from measurements of the cleaned bone taken, insofar as possible, from full-grown animals. Body weight and length are also recorded, though these are usually estimates based on the known size of other individuals of the same species. An attempt has been made to compare the size of a "typical" full-grown baculum with the size of a "typical" full-grown male body.

We gratefully acknowledge the help of zoologists whose names are given in the sources to table 1; also to Ancel M. Johnson, statistician.

The ratio: baculum weight/body weight varies greatly with the species, in the order of 1 to 183 (table 2). The ratio: baculum length/body length varies in the order of 1 to 3.25. During evolutionary development of the pinnipeds, baculum weight has increased greatly over baculum length. We suppose that increased weight of the baculum, and its corollaries cross-section diameter and strength, have had survival value for certain species.

An important factor operating on baculum size seems to be the environment in which copulation takes place. Insofar as we understand the breeding habits of pinnipeds, the forms listed in table 2 can be arranged in two groups: first, those which copulate in water or on ice, normally with body surface wet; and second, those which copulate on land, normally with body surface dry. Members of the first group have a relatively large baculum; members of the second group a small one. (It would be dangerous to assume, however, that copulation in water has had an exclusive evolutionary influence on development of the baculum, for in cetaceans, the most aquatic of all mammals, a baculum is entirely lacking!)

The elephant seal, heaviest in body, has relatively the lightest baculum (table 2). From this example alone we might be led to suppose that, during the evolution of body size, baculum weight has lagged behind. However, when all of the 17 genera of table 2 are analyzed with respect to the relationship between baculum weight and body weight, the correlation proves to be insignificant ($r = -.218$, when significance at the 95 % level would need to equal $\pm .482$).

An arrangement of species by weight of baculum (table 2) tends to bring phylogenetically related species together. This is another way of saying that baculum size has followed approximately the course of evolution of other body characters, such as skull and dentition, upon which phylogeny of the pinnipeds is based. At the head of table 2 is *Odobenus,* representing the family *Odobenidae;* then 11 genera representing Phocidae; then 5 representing Otariidae; and finally Mirounga which, though classed with the Phocidae, is in some respects a taxonomic riddle.

*Table 1*

**Baculum size in pinnipeds**

| Species | Baculum specimen number | Age | Baculum length (mm) | Baculum weight (g) | Body length (cm) | Body weight (kg) | Source 1 |
|---|---|---|---|---|---|---|---|
| *Otaria byronia* (South American sea lion) | — | adult | — | — | 246 | 522 | a |
| *Eumetopias jubata* (Stellers sea lion) | BDM 300 | >10 | 206 | 69.4 | 316 | 938 | b |
| *Zalophus californianus* (California sea lion) | — | 8—10 | 121 | 11.3 | 177 | 170 | c |
| *Neophoca hookeri* (New Zealand sea lion) | MNHN | — | 260 | — | — | — | d |
| *Arctocephalus pusillus* (South African fur seal) | BM (NH) 1953 4. 9. 1 | subadult | 123 | 9.9 | 217 | 143 | e |
| *Arctocephalus tropicalis* (Kerguelen fur seal) | — | adult | 128 | 12.5 | 195 | 160 | f |
| *Callorhinus ursinus* (Northern fur seal) | — | >10 | 142 | 14.5 | 193 | 250 | g |
| *Odobenus rosmarus* (Walrus) | — | adult | 540 | 980.0 | 293 | 1246 | h |
| *Odobenus rosmarus* (Walrus) | A 114 | 20 | 560 | 1030.0 | 320 | — | i |
| *Phoca vitulina* (Harbor seal) | — | adult | 137 | 16.4 | 156 | 104 | j |
| *Pusa hispida* (Ringed seal) | KWK 58—33 | adult | 118 | 7.9 | 114 | 43 | k |
| *Histriophoca fasciata* (Ribbon seal) | BDM 543 | adult | 142 | 16.4 | 135 | 76 | l |
| *Pagophilus groenlandicus* (Harp seal) | BM (NH) 1951 11.28.2 | adult | 185+ | 66.0+ | 172 | 140 | m |
| *Halichoerus grypus* (Gray seal) | B 3 | 13 | 163 | 41.5 | 236 | 204 | n |
| *Erignathus barbatus* (Bearded seal) | KWK 58–23 | adult | 140 | 28.8 | 211 | 239 | o |
| *Monachus schauinslandi* (Hawaiian monk seal) | BDM 490 | ca. 21 | 183 | 41.1 | 214 | 172 | p |
| *Lobodon carcinophagus* (Crabeater seal) | 142 | adult | 220 | 35.7 | 225 | 179 | q |
| *Hydrurga leptonyx* (Leopard seal) | 655, 662 | adult | 233 | 60.3 | 297 | 220 | r |
| *Leptonychotes weddelli* (Weddel seal) | 37 | adult | 218 | 54.3 | 255 | 286 | s |
| *Cystophora cristata* (Hooded seal) | ZMH 3040 | ca. 8 | 210 | 32.0 | 280 | 370 | t |
| *Mirounga leonina* (Southern elephant seal) | — | 6—8 | 331 | 109.0 | 474 | 2550 | u |
| *Mirounga angustirostris* (Northern elephant seal) | SDNHM 7296 | adult | 274 | 106.0 | 475 | 2268 | v |

**Sources of data for table 1**

a Length of a Falkland Island specimen measured by HAMILTON (1939 b, p. 125); weight of another estimated at "circa 1150 pounds" by BRUCE (1915, p. 173); no baculum available.

b Collected on St. Paul Island, Alaska, 6 June 1949, by KENYON.

c Collected at San Diego, California, 3 January 1951, by KENYON, who estimated it at 350—400 pounds.

d Baculum of "*Eumetopias hookeri*" in Museúm National d'Historie Naturelle, fide CHAINE (1926, p. 151).

e Baculum length and condylobasal length (256 mm) fit well into "Group H" of RAND (1956), upon whose authority body size data are recorded.

f Collected on Bird Island, South Georgia, by W. N. BONNER *(in lit.)*. Maximum data are recorded from the following specimens: body length (FS 60), body weight (FS 23), baculum length and weight (FS 56); all specimens in British Museum.

g Baculum length from specimen BDM 366 collected on St. Paul Island, Alaska, 13 August 1949, by KENYON; body size estimated at 90 percent of maximum known size of other adults (SCHEFFER and WILKE, 1953, p. 133, 135). Another baculum of 136 mm and 14.5 g was recorded by SCHEFFER (1950, p. 391). The weight of this baculum is used in calculating the ratio of baculum length to body weight.

h Baculum only found on beach of St. Paul Island, Alaska, in summer of 1954, by KENYON; body size estimated at 80 percent of maximum known size of other adults (BUCKLEY, 1958, p. 5).

i Collected by D. E. SERGEANT; body size "at least 1200 kg" *(in lit.)*.

j Collected on Amchitka Island, Alaska, 29 September 1955, by KENYON; body size estimated at 90 percent of maximum known size of other adults (SCHEFFER, 1958, p. 145).

k Collected on Little Diomede Island, Alaska, 27 May 1958, by KENYON; body length estimated from known length of another male of similar size taken at the same time; weight estimated at 90—100 pounds.

*Table 2*

**Ratios: baculum weight/body weight and baculum length/body length**

Data from table 1 rearranged by decreasing ratio of baculum weight

| Species | Percent weight baculum / body | Percent length baculum / body | Copulation in water | Copulation on land |
|---|---|---|---|---|
| *Odobenus rosmarus* | 0.0787 | 18.43 | — | ? |
| *Pagophilus groenlandicus* | 0.0471 | 10.76 | ? | — |
| *Lobodon carcinophagus* | 0.0357 | 9.78 | × | — |
| *Hydrurga leptonyx* | 0.0274 | 7.85 | ? | — |
| *Monachus schauinslandi* | 0.0239 | 8.55 | × | — |
| *Histriophoca fasciata* | 0.0216 | 10.52 | × | — |
| *Halichoerus grypus* | 0.0203 | 6.91 | × | × |
| *Leptonychotes weddelli* | 0.0190 | 8.55 | × | — |
| *Pusa hispida* | 0.0184 | 10.35 | ? | — |
| *Phoca vitulina* | 0.0158 | 8.78 | × | — |
| *Erignathus barbatus* | 0.0121 | 6.63 | ? | — |
| *Cystophora cristata* | 0.0086 | 7.50 | × | — |
| *Arctocephalus tropicalis* | 0.0078 | 6.56 | — | × |
| *Eumetopias jubata* | 0.0074 | 6.52 | — | × |
| *Arctocephalus pusillus* | 0.0069 | 5.67 | — | × |
| *Zalophus californianus* | 0.0066 | 6.84 | — | × |
| *Callorhinus ursinus* | 0.0058 | 7.36 | — | × |
| *Mirounga angustirostris* | 0.0047 | 5.77 | — | × |
| *Mirounga leonina* | 0.0043 | 6.98 | — | × |

l Collected on Little Diomede Island, Alaska, about 17 June 1958, by KENYON; body size estimated at 80 percent of maximum known size of other adults (SCHEFFER, 1958, p. 146).
m Body size from SIVERTSEN (1941); baculum size from D. E. SERGEANT *(in lit.)*. The British Museum specimen, for which no data are given in the table, is represented by a baculum of 180 mm and 34.3 g.
n Body weight estimated; age assigned from tooth-layer count (H. R. HEWER, *in lit.)*. Grace HICKLING reported *(in lit.)* a baculum of 170 mm (Hancock Museum no. 46).
o Collected on Little Diomede Island, Alaska, 23 May 1958, by KENYON.
p Collected on Midway Atoll, Hawaii, 2 February 1957, by KENYON and D. W. RICE.
q DIDIER (1953, p. 26); the largest af 3 bacula, all adult. Body size estimated at 80 percent of maximum known size of other adults (SCHEFFER, 1958, p. 148).
r HAMILTON (1939a, p. 257, pl. xi); mean of two specimens, each 297 cm in length. Body size estimated at 80 percent of maximum known size of other adults (SCHEFFER, 1958, p. 148). LAWS (1957, p. 50) measured a longer baculum, 300 mm, from a 285 cm seal.
s DIDIER (1953, p. 23); body size estimated at 80 percent of maximum known size of other adults (SCHEFFER, 1958, p. 147).
t Captured in the Faroes in 1954; died Bremerhavener Tiergrotten in 1956; age 14—15 years (ERNA MOHR, in lit.). A Jan Mayen specimen reported by these authors had a baculum of 205 mm and 38 g.
u Mean of four specimens (M 84, M 107, M 111, M 120), from LAWS (1953, p. 39—40) and JUDITH E. KING *(in lit.)*. Largest baculum, 349 mm, 125 g.
v HUEY (1930, p. 229) estimated the weight at "5,000 pounds"; data on the baculum are from HUEY *(in lit.)*.

## Summary

In 20 species of pinnipeds the ratio: baculum size/body size is 183 times greater in *Odobenus* than in *Mirounga*. A relatively large baculum is correlated with copulation in water; a small one with copulation on land. The ratio tends to vary with family groupings.

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*Anschriften der Verfasser:* Dr. VICTOR B. SCHEFFER und KARL W. KENYON, Marine Mammal Biological Laboratory, U. S. Fish and Wildlife Service, Bulding 192, Sand Point Naval Air Station, Seattle 15, Washington

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Experience Paper No. 11

# CLIMATIC PARAMETERS AND THE HAWAIIAN SKIPJACK FISHERY

By

GUNTER R. SECKEL
U. S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

## Abstract

Associations between the availability of skipjack to the Hawaiian fishery and their physical environment became apparent in a study of the oceanographic climate in terms of circulatory systems, associated water types, and the seasonal displacement of their boundaries. Good fishing success in Hawaii does not only depend on the right type of water (California Current Extension) bathing the islands but also on the right dynamic conditions as reflected by the shape of the heating curve and the time of initial heating (February) at Koko Head, Oahu. The index to be associated with skipjack availability was the heat advection, which contains time as a dimension. This led to the conclusion: If biological processes which contain time as a dimension are to be related to the environment, then, to be dimensionally correct, associated environmental parameters must also contain time as a dimension.

# LES PARAMETRES CLIMATIQUES ET LES PECHERIES DE BONITES A VENTRE RAYE DES EAUX HAWAIIENNES

## Résumé

L'étude du climat océanographique du point de vue des systèmes de circulation, des types d'eau associés et du déplacement saisonnier de leurs limites, a fait ressortir des rapports entre la disponibilité des bonites à ventre rayé dans les pêcheries hawaiiennes et les facteurs physiques du milieu. Le succès de la pêche dans les eaux hawaiiennes ne dépend pas seulement de la présence autour des îles du type d'eau approprié (prolongement du Courant de Californie), mais également des conditions dynamiques convenables, exprimées par le dessin de la courbe des variations thermiques et par l'époque où commence le réchauffement (février) à Koko Head (Oahu). L'indice devant être associé à la disponibilité des bonites à ventre rayé est l'advection thermique, qui renferme le facteur temps. D'où la conclusion suivante: si les processus biologiques, qui s'inscrivent dans le temps, doivent être rattachés à l'environnement, les paramètres écologiques connexes doivent aussi, pour être exacts, comporter le facteur temps.

EP/11

# LOS PARAMETROS CLIMATICOS Y LA PESQUERIA HAWAIANA DE BARRILETE


## Extracto

Las conexiones entre la disponibilidad de barrilete o bonito de altura en la pesquería hawaiana y su medio ambiente físico se pusieron de manifiesto en un estudio del clima oceanográfico en función en función de los sistemas circulatorios, los distintos tipos de agua respectivos y el desplazamiento estacional de los límites de ellos. El éxito de la pesca en Hawai no solamente depende de la existencia del tipo apropiado de agua (Prolongación de la Corriente de California) que baña las islas, sino también de las apropiadas condiciones dinámicas reflejadas en la forma de la curva de variaciones térmicas y el tiempo del calentamiento inicial (febrero) en Koko Head, Oahu. El índice que hay que asociar con la disponibilidad de barrilete es el de la advección del calor, en el que se incluye el tiempo como una de las dimensiones. Esto llevó a la conclusión de que si los procesos biológicos que contienen el tiempo como una dimensión han de ser relacionados con el medio ambiente, entonces para que sean dimensionalmente correctos, los correspondientes parámetros ambientales deben también incluir el tiempo como una dimensión.

Traditionally, when marine biological distributions are considered in terms of their physical environment, they are related to properties such as the temperature, salinity, or nutrients which do not contain the dimension of time. In addition to these, however, there are parameters which express the time rate of change of properties, reflecting processes, and others which may express accelerations, reflecting forces in the environment. Such parameters contain the dimensions of $T^{-1}$ or $T^{-2}$ and may be important if such biological processes as reproduction, migration, and animal behavior are to be related to the physical environment. In recent years the discovery of associations between the availability of skipjack in the Hawaiian fishery and certain oceanographic parameters lends support to this view.

The Hawaiian skipjack fishery is located in an area where the annual range of surface temperature is approximately 3° C. and the annual range in surface salinity is approximately 0.6 ‰. Seasonal variations in the standing crop of zooplankton have not been clearly defined and seasonal variations in the concentration of nutrients such as phosphates, have not been demonstrated. These small changes are not believed to account for the seasonal and annual changes in the availability of skipjack as reflected in the landings of the fishery. The former range from 200,000 pounds per month in winter to more than 2,000,000 pounds per month in summer and the latter from 6,000,000 pounds per year as in 1957, to 14,000,000 pounds per year as in 1954.

Changes in the environment which may explain the changes in the fishery, however, become apparent when the oceanographic climate is studied in terms of circulatory systems, associated water types, and the seasonal displacement of their boundaries. Of importance in Hawaii are the North Pacific central and the North Pacific equatorial water types and the transition zone between these, the California Current Extension (Fig. 1). It was shown (Seckel, 1961) that the boundary between the California Current Extension with a salinity of less than 34.8 ‰ and the North Pacific central water with a salinity of more than 35 ‰ is well defined by a relatively sharp salinity gradient and generally lies just south of the islands during late autumn and early winter. During February or March it begins a northward movement passing through the islands during spring and reaching its northern position just north of the islands during July or August, when it begins its southward retreat. The movement of the boundary is reflected in changes of the surface salinity which are monitored by regular sampling near Koko Head, Oahu.

On the basis of heat budget considerations, four climatic periods which affect the Hawaiian waters were also deduced: (1) a warm advection[1/] period during March and April, (2) a cold advection period peaking in July, (3) a second cold advection period peaking in October or November, and (4) a third cold advection period peaking during January or February. The warm advection period coincides with the initial northward movement of the salinity boundary. Under the influence of the spring and summer intensification of the trade wind system, the California Current Extension also intensifies and spreads, which is reflected by the summer cold advection period and the continued northward displacement of the salinity boundary. The autumn contraction and slackening of the California Current Extension results in the southward movement of the salinity boundary and the second cold advection period. The winter cold advection period is believed to be associated with an intensification of the circulation in the North Pacific central system.

Processes such as heat advection directly affect the rate of change of surface temperature, and when the latter is plotted versus time, a "characteristic heating curve" is obtained (Seckel, 1961). In the Hawaiian area the characteristic fluctuations primarily reflect changes in heat advection, so that they can be used to identify the advection periods described above. The characteristic heating curve for Koko Head, Oahu, based on 1951-1960 surface temperatures, is shown in Fig. 2. The fluctuations are characteristic for this location and may vary in magnitude or be displaced in time but can be identified in the heating curves of most of the years for this period. The spring warm and summer cold advection periods, which are of particular interest in this paper, are labeled in the figure. The time of initial warming, which coincides approximately with the beginning of the warm advection period and northward movement of the salinity boundary, is also indicated.

It is now possible to examine the Hawaiian skipjack fishery in terms of the climatic picture as reflected by these new indices. Some of the results to be presented were previously published

1/ Warm or cold advection means a change of temperature due to the movement of warmer or colder water into an area, respectively.

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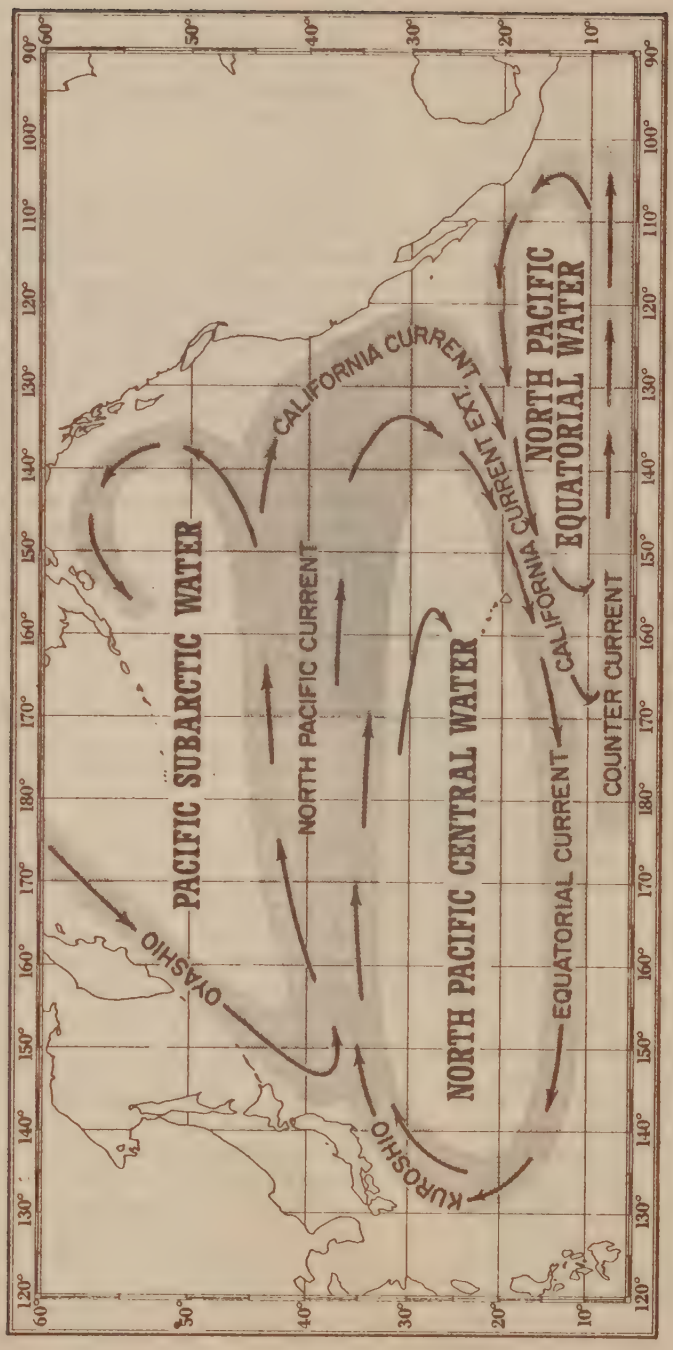


Fig. 1 Schematic chart of the major North Pacific water types and currents

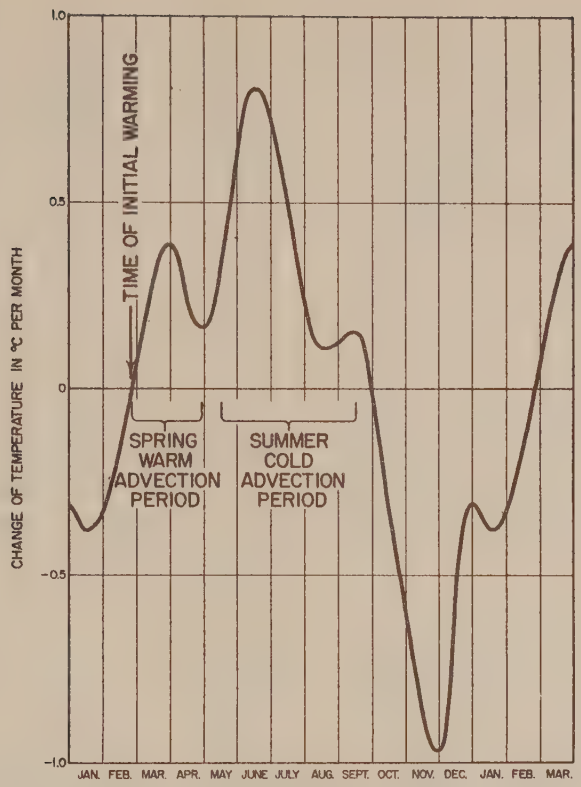


Fig. 2 Characteristic heating curve, Koko Head, Oahu

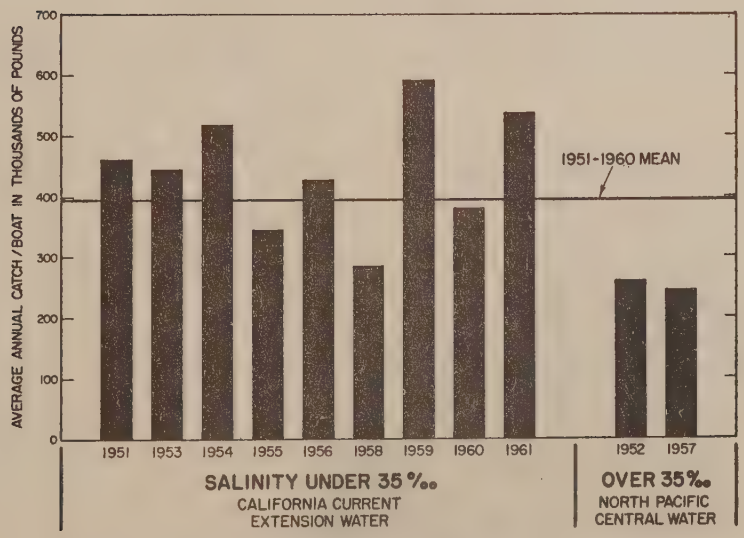


Fig. 3 Hawaiian skipjack landings, average annual catch per boat, as related to summer salinities

by Seckel and Waldron (1960). Considering summer salinities, it was found that during summers when the California Current Extension bathed the islands the annual skipjack landings were above average, whereas when the North Pacific central water bathed the islands during the summer, the annual landings were below average (Fig. 3). Three exceptions to this rule appear in the graph. The catch for 1958 is placed on the California Current Extension side of the graph because a salinity of 35 ‰ was chosen as an index of the salinity boundary. During that year, however, the minimum summer salinity was approximately 34.9 ‰, so that California Current Extension water did not bathe the islands and the association held true. The other exceptions, during 1955 and 1960, when landings were below average although California Current Extension water bathed the islands, indicate that other factors besides the type of water are of importance.

During the course of the climatic study it became apparent that the annual skipjack landings in Hawaii, reflecting availability, were also associated with the time of initial warming at Koko Head. Whenever this occurred in March, landings were below average, whereas when it occurred in February, landings were above average (Fig. 4). The time of initial warming is associated with the warm advection period and shows that dynamic conditions favorable to the fishery must be present well before the season begins. This association, therefore, provides the fishery with a predictive index which has so far been without exceptions.

Additional associations between the environment and the fishery become apparent when the 10-year Koko Head heating curve is examined together with the monthly skipjack landings (Fig. 5).

The shaded portions in each year indicate approximately the spring warm and summer cold advection periods, and the vertical bar, the time of initial warming. First, comparing the upper and lower panels, it is apparent that the peak catch period in each year coincides with the summer cold advection period. Then, the heating curves of 1954, 1959, and 1961 exhibit similarities: The time of initial warming occurred well before the end of February, and pronounced fluctuations, reflecting intensified dynamic processes, occurred between February and June. During these years landings were also well above average. There were, however, distinct differences in both the peak monthly landings per boat and the length of the peak fishing period.

Peak landings in terms of catch per boat per month were 142,000 pounds in 1954 and 119,000 pounds in 1959. The length of peak fishing as measured by the time between maximum rate of increase and decline in monthly landings was 2 and 3 months during these years, respectively. A reduction in peak catch rates in 1959 was therefore compensated by a longer fishing period. Looking into the length of the peak fishing period, one finds that these also correspond with differing lengths of the summer cold advection periods of 2.5 and 5 months during 1954 and 1959, respectively. As in 1954, the shorter fishing period of 2 months during 1961 also corresponded with a shorter cold advection period of 3.5 months.

Just as 1954 and 1959 exhibited similarities in the spring and summer portions of the heating curve, so the years following, 1955 and 1960, exhibited similarities: the initial heating began in March, the characteristic February to May fluctuations were absent, and heating peaked during April-May and then declined. The heating curves for these years are characteristic of the type to be found south of the islands (Seckel, 1961) and therefore reflect a northward displacement of the oceanographic climate. They also indicate that the effect of the intensified dynamic processes of 1954 and 1959 continued into the following year. This, then, indicates that 1955 and 1960, the exceptions in the relation between summer salinities and availability of skipjack, were years when the dynamics of the system was different from that usually found in the Hawaiian area.

This was also true for 1957, when initial warming occurred in March, the characteristic February to May fluctuations were absent, and peak heating in June was higher than average. In this case, the curve resembles one normally to be found north of the islands and therefore reflects a southward displacement of the oceanographic climate, as confirmed by high summer salinities. Therefore, during the poorest fishing year of the decade, neither the type of water nor the dynamic factors were those which are to be found during a good fishing year.

The Koko Head heating curve indices, the summer cold advection period, time of initial heating, pronounced spring fluctuations in the heating curve, the length of the summer advection period, and the heating curves characteristic of regions to the north or south of the islands (1957, 1955, 1960) reflect the dynamics of the environment.

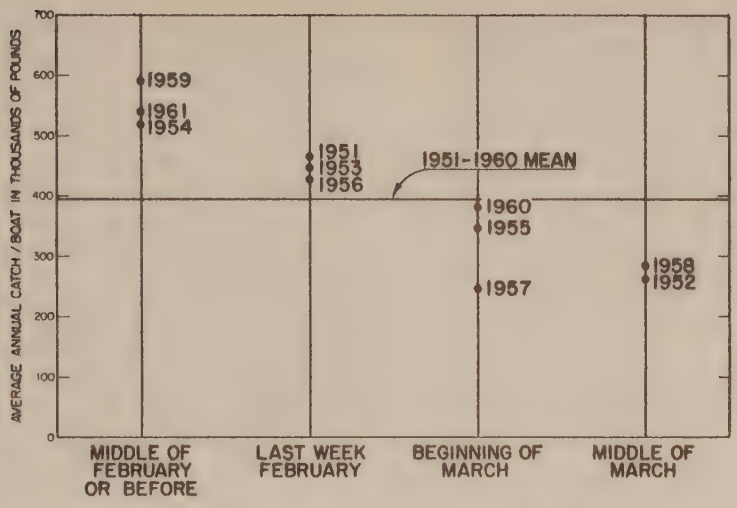


Fig. 4 Hawaiian skipjack landings, average annual catch per boat, as related to time of initial warming

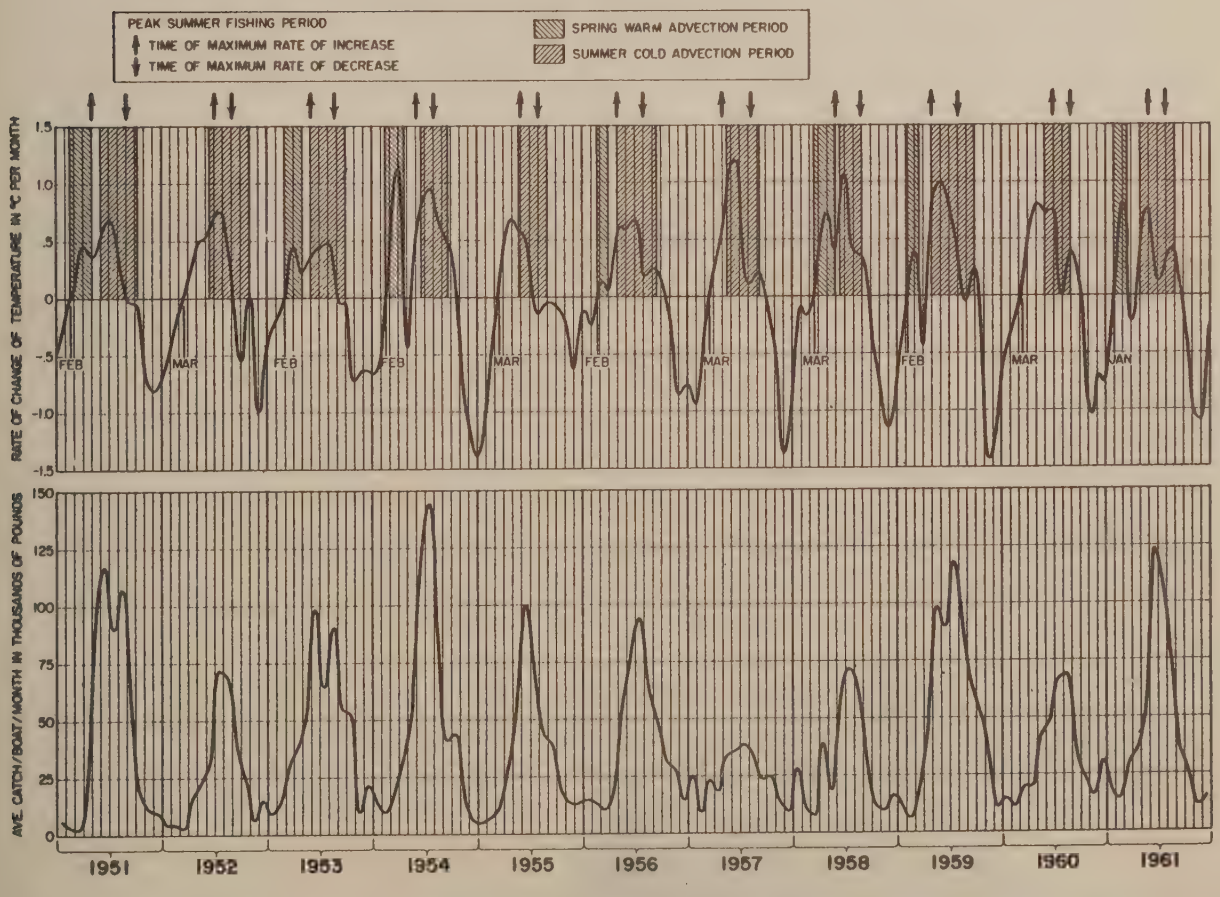


Fig. 5 Upper panel: Koko Head heating curve 1951-1961; lower panel: Hawaiian skipjack landings 1951-1961, in average catch per boat per month. (Heating curve Jan. 1951-Nov. 1955 obtained from surface water temperatures near Oahu)

It is evident, therefore, that in addition to a specific type of water, the summer skipjack population is also associated with a dynamic feature in the environment. The nature of the linkage between the fish and the environment, or even the nature of the dynamic feature, is not known at the present time. It is possible that they are produced by the barrier effect of the island chain in a varying current field and may involve the island wake and the boundary separating the North Pacific central from the California Current Extension water.

The index to be associated with the skipjack availability has been the heat advection, which contains the dimension $T^{-1}$ and is directly reflected in the time rate of change of temperature, which also contains the dimension of $T^{-1}$. Indeed, the fluctuations in the heating curve reflect accelerations containing the dimension $T^{-2}$ and therefore are in response to forces acting on the environment. This points to an important method of approach in ecological studies, when biological processes are to be related to the physical environment. The former imply time rates of change and accelerations, i.e., first and second time derivatives containing dimensions $T^{-1}$ and $T^{-2}$, and therefore, to be dimensionally correct, associated environmental parameters must contain the same derivatives with respect to time. Thus, investigations of parameters containing the dimensions $T^{-1}$ and $T^{-2}$ may lead to new associations and to a better understanding of ecological problems and their solution.

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# INDEX OF CONDITION AND PER CENT SOLIDS OF RAFT-GROWN OYSTERS IN MASSACHUSETTS

William N. Shaw

Fishery Biologist (Research)
Bureau of Commercial Fisheries
Biological Laboratory
Oxford, Maryland

ABSTRACT

Oysters were suspended from a Fiberglas raft in Taylors Pond, Chatham, Massachusetts from September 1959 to October 1960. The index of condition showed a low of 8.8 in July 1960, just after spawning, and highs of 14.6 and 14.5 in October 1959 and September 1960 respectively. The average monthly index for the 13-month period was 12.2. The seasonal cycle of per cent solids was similar to that reported for oysters in Upper Chesapeake Bay. Oysters must be planted on the bottom at the end of the first year of suspension to make shells thicken and to eliminate losses due to oysters breaking away from strings during the second year of suspension.

At the 1960 meeting of the National Shellfisheries Association, I reported (Shaw, 1962) on a study dealing with the possibility of commercially rearing oysters, Crassostrea virginica, suspended from rafts in the tidal waters of Massachusetts. The results of the experiment demonstrated that seed oysters, which were suspended from a raft for their first year of life and then planted on the bottom for an additional year, grew large enough to sell on the half-shell market. In these waters it normally takes from 4 to 5 years for seed oysters to reach a market size of 3 inches when bottom culture is used exclusively.

The question of quality of the meat of raft-grown oysters as compared with oysters grown on the bottom remained unanswered. The purpose of this note is to present the results of an experiment conducted from the fall of 1959 to the fall of 1960 on the index of condition and per cent solids of oysters suspended from a raft. To evaluate the data, the index of condition and the percentage of solids of the raft-grown oysters were compared with those reported for oysters grown in other areas.

## DESCRIPTION OF AREA AND METHODS

The experiment was conducted in Taylors Pond, West Chatham, Massachusetts. The pond is about 400 yards long and 200 yards wide. Its depth ranges from 1 to 9 feet at mean low water. The range of tide is about 4 feet. From 1959 through 1960, salinity varied from 28.2 o/oo to 31.5 o/oo, surface water temperature fluctuated from a summer high of 26.7 C to a winter low of -0.1 C, and average pH was 7.9.

The oysters used in the experiment came from Mill Creek, a tidal outlet of Taylors Pond. The creek runs for about one-half mile before emptying into Nantucket Sound. Its bottom is hard sand changing to soft mud near the banks. Several sand bars, which are exposed at low tide, are found along the length of the creek.

Seed oysters for the experiment were obtained by placing chicken-wire bags, each containing one-half bushel of bay scallop shells, on several sand bars. In 1958, setting occurred between July 18 and July 23. On September 2 of that year, samples of spat were strung on either polyethylene tubing, nylon rope, or parachute cord and suspended from a Fiberglas raft (Shaw, 1960). Of the three materials, the nylon rope proved the most satisfactory.

The index of condition was computed by dividing the dry weight of the meat (grams) by the volume of the shell cavity (milliliters) x 100 (Grave, 1912; Higgins, 1938). The per cent solid of the oyster meat was determined by dividing the total dry weight of meat by the total wet weight of the meat x 100 (Engle, 1950). Once a month from September 1959 to October 1960 (except for January 1960), 50 raft oysters were cleaned of all fouling plants and animals. The following measurements were taken: total volume, shell volume, wet weight of meat and dry weight of meat. The oysters were treated individually and a mean, standard deviation, and standard error of the mean for the group was determined in each category.

## RESULTS

Fig. 1-B shows the seasonal changes of the index of condition for raft oysters. In September 1959, the index was 13.3. This value rose to 14.6 in October. During the winter when the oysters were hibernating the index showed little change though a slight decline was observed. On examination of Fig. 1-C it is apparent that the decline was not significant. Between March and April the index showed a sharp decline. The drop occurred when the water temperature rose from 2.5 C to 9.5 C (Fig. 1-A).

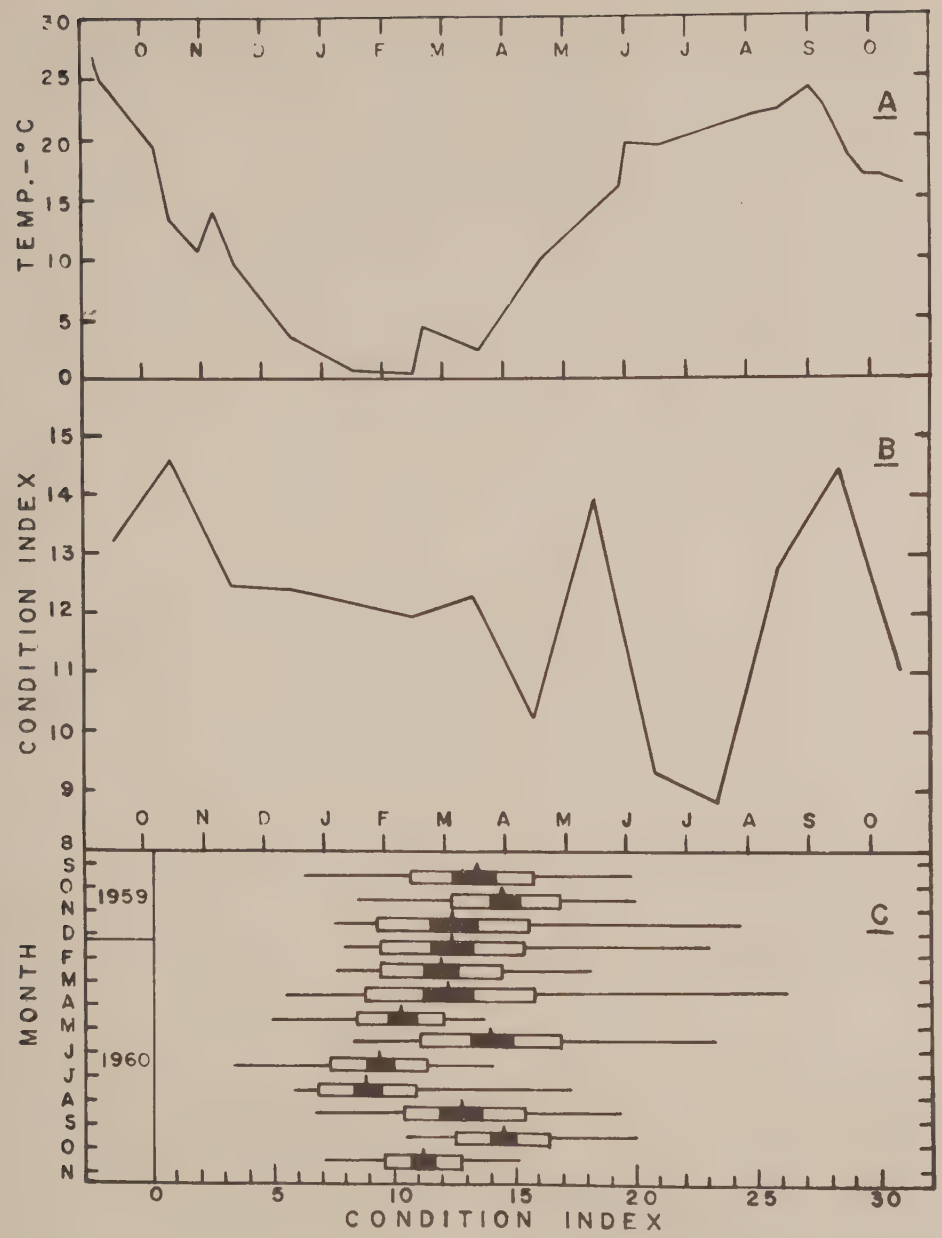


Fig. 1. A. Changes in water temperature in Taylors Pond, 1959-1960. B. Monthly index of condition of raft-grown oysters from September 1959—October 1960. C. Graphic analysis of index of condition: The monthly range, horizontal line; the mean (M), small narrow triangle; 2 standard errors of the mean, the black bar on either side of M; and one standard deviation, one-half black bar plus white bar on either side of M.

From April 18 to May 16 the index of the raft oysters climbed significantly from 10.3 to 14.0. From examination of the raft-grown oysters, this period corresponded to the time when gonadal development was taking place. As the temperature approached 20 C in the middle of June, initial spawning occurred. The oysters continued to show signs of spawning through the first part of July. A corresponding drop in index of condition took place during this period from 14.0 in mid-May to 8.8 in mid-July. Following spawning the index rose rapidly to 14.5 by September 19. The index then decreased significantly to 11.2 in October. The index of condition was never below 8.8. The average for the 13-month period was 12.2.

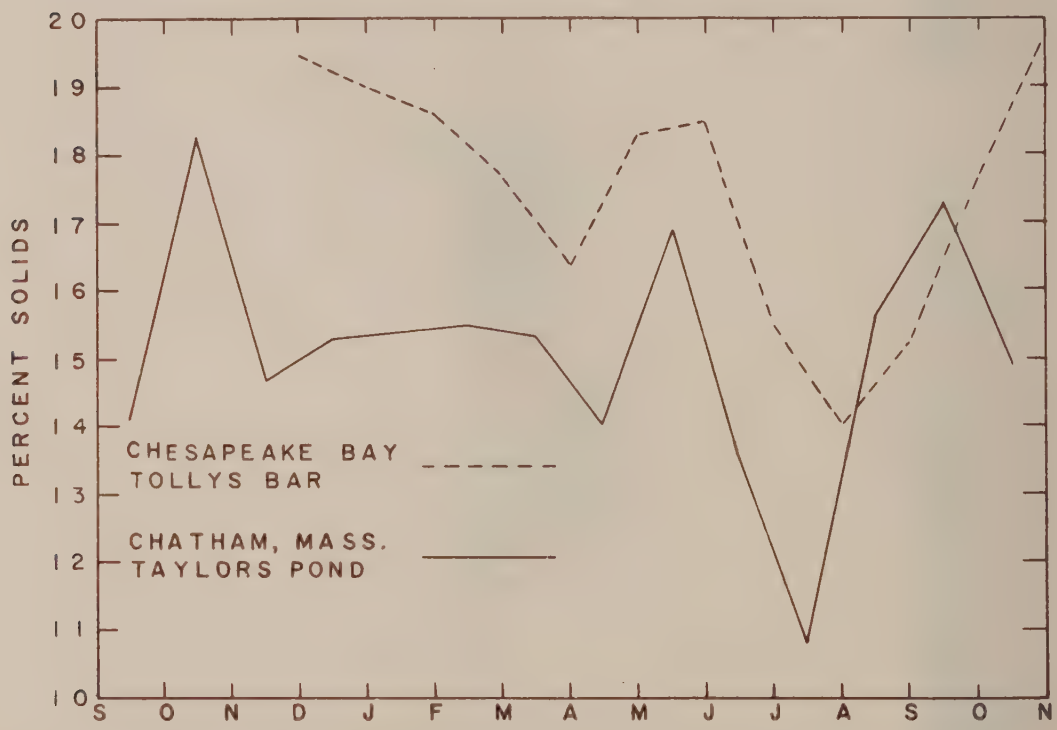


Fig. 2. Monthly averages of per cent solids for raft-grown and Upper Chesapeake Bay oysters.

In Fig. 2 the seasonal cycle of the per cent solids of raft oysters is compared with that found by Engle (1958) for oysters growing on Tollys Bar, Upper Chesapeake Bay, Maryland. The seasonal cycles of per cent solids for the two groups appear to be similar. In both, there is a winter decline which is followed by an early spring increase. During the summer a decline related to spawning occurs, and then an increase in the per cent solids takes

place during the fall. The cycles of per cent solids and index of condition for the oysters suspended from the raft were also found to follow similar seasonal patterns.

## DISCUSSION AND SUMMARY

Medcof and Needler (1941) observed that the index of condition of Canadian oysters showed little change when the water temperature was below 5 C. The index was observed to fall at water temperatures between 5 C and 15 C and then rise again at water temperatures between 15 C and 20 C. These authors further found that above 20 C spawning took place among the Canadian oysters with a corresponding fall in the index. As the water temperature fell from 20 C to 15 C, fattening occurred and the index increased rapidly, but when the temperature dropped below 15 C the index also dropped.

The seasonal cycle of the condition index for raft oysters was similar to that found for Canadian oysters. The one exception was the sudden fall in the index of the suspended oysters in September and October 1960 when the water temperature was dropping from 20.5 C to 16.6 C. At corresponding temperatures the index of the Canadian oysters was found to increase. It should be mentioned that the index of condition for raft oysters was determined for just one year and if more years could have been included some modification in this pattern might have been found. It is doubtful, however, that the seasonal cycle of the per cent solids would vary to any extent since it compared closely with that found by Engle (1958) over a seven-year period.

The index of condition for raft oysters was generally much higher than that reported for oysters in Chesapeake Bay (Galtsoff, 1947; Engle, 1950; Haven, 1959). The indices for the suspended oysters also compared favorably and, in many cases, were higher than those found for Canadian oysters, C. virginica, grown in Bras d'Or Lakes, N. S., and Shediac Bay, N. B. (Medcof and Needler, 1941). On the basis of the comparison it can be stated that the index of condition of raft oysters was high.

Though the condition of raft oysters was high, the thinness of shell due to rapid growth made them unsuitable for the half-shell market. It is therefore necessary to place them on the bottom at the end of the first year in order that the shells will thicken. It was also observed in this experiment that many oysters broke away from

the strings and fell to the bottom during the second year of suspension. The danger of such losses increases the need for planting the raft oysters on suitable grounds at the end of the first year of suspension.

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# A METHOD OF TAGGING CHANNELED WHELKS

By WILLIAM N. SHAW

Fishery Biologist (Research), U. S. Fish and Wildlife Service,
Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland

Both the channeled whelk, *Busycon canaliculatum* (Linné), and the knobbed whelk, *B. carica* (Gmelin), are known predators of oysters. Carriker (1951) found that the predation rate for both species of *Busycon* in aquaria ranged from 0.8 to 2.7 oysters (1.0 - 7.8 cm in shell height) consumed per whelk per week. In field studies at Oyster Pond River, Chatham, Massachusetts, Shaw (1960) found that *B. canaliculatum,* placed in a wire cage with oysters greater than 7.6 cm. in height, consumed 0.3 oysters per whelk per week.

Shaw (1960) also noted in field observations that the majority of channeled whelks could be removed from oyster bottoms in the spring in wooden traps baited with partly crushed horseshoe crabs, *Limulus polyphemus.* The high rate of capture on oyster beds at the beginning of each trapping season indicated that the whelks had moved in from other areas during the previous year.

With the intent of tracing the movements of the channeled whelk, I tagged 100 individuals and released them at the mouth of Oyster Pond River, about ¼ mile down stream from the nearest oyster bed, on June 10 and June 13, 1960. The purpose of this note is to describe the method of tagging and the direct effects of the tag on the whelk.

Each whelk was tagged as follows: Large polyethylene tubing was cut open and rectangles, ¾ x ½ inch, were cut from this. A number was stamped on and a hole was punched in each rectangle. Two holes, 2 mm. in diameter and 10 mm. apart, were drilled through the shell of the whelk about one inch inside the outer lip to the body whorl and just beneath the sutural canal. A piece of polyethylene tubing, 1 mm. in diameter was looped through the holes in the shell and through the hole in the tag. The tag was then tied in place by joining the ends of the tubing with a standard square knot (figs. 1 & 2, A & B). Prior to release of the whelks, the shell height (spire tip to siphon tip) and maximum diameter (outer lip to the opposite

side) of each was measured to the nearest millimeter.

In February 1962, two tagged whelks were recovered. The empty shell of one was found on the beach at the mouth of Oyster Pond River just opposite the point of release. The broken shell of the second whelk with the tag intact was found by an oysterman on his barge one mile up river from the area of release. Probably this individual had been dropped on the barge by a seagull. Since I do not know where the seagull originally found the whelk, the exact movement of this snail is not known.

The following changes were noted on the shells of the two whelks: In one shell the loop of the plastic tubing inside the body whorl had been completely covered by new shell thus cementing the tubing in place (fig. 3). This whelk had increased in shell height from 158 mm. to 172 mm. and in maximum diameter from 90 mm. to 96 mm. In the other whelk the inner loop of plastic tubing was only partially covered with new shell (fig. 4). Probably the latter whelk died or was killed before completely covering the tubing. Since this individual was not intact, shell measurements could not be obtained.

Probably the loop of tubing inside the shell irritated the mantle of the whelk stimulating the snail to secrete shell over the tubing. After the loop was covered, the tubing became sealed in place and probably would remain there throughout the whelk's life.

These observations suggest that this is a suitable method of tagging whelks for studies of their growth rates and migration patterns in the field.

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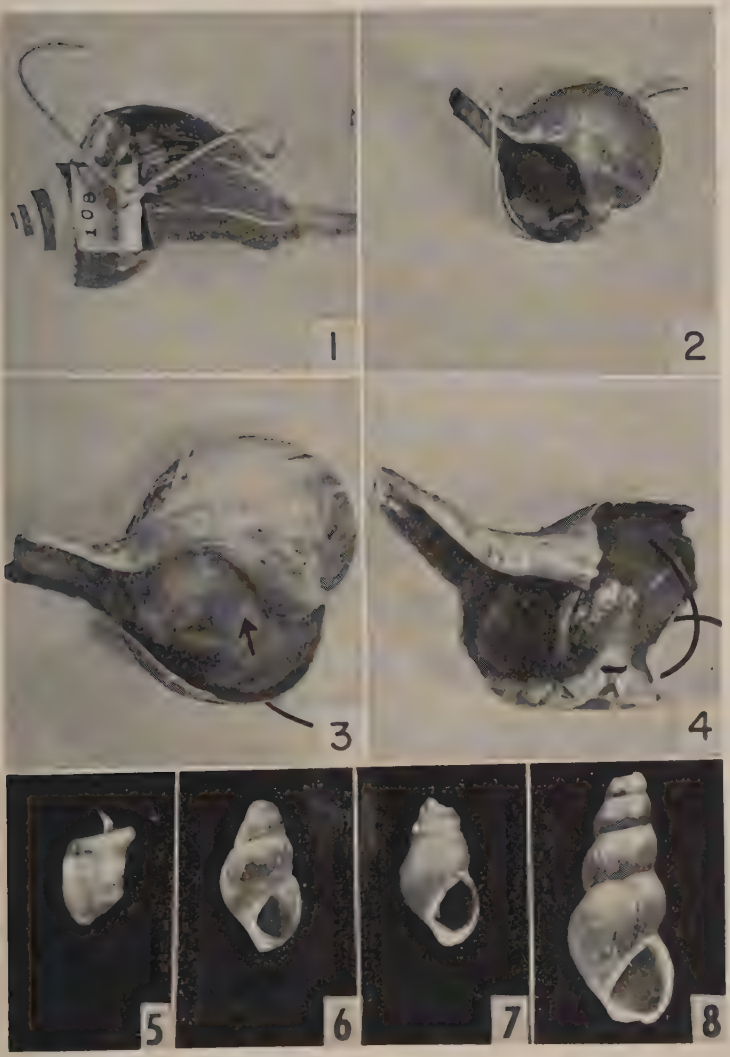


Figs. 1-4, *Busycon canaliculatum* (Linne). 1 & 2: Showing attachment of the tag. 3: Arrow points to area where inner loop of plastic tubing has been covered over with shell. 4: New shell partially covering inner loop of plastic tubing. Figs. 5-8, *Goniobasis*. 5: Fragment of body whorl from RB285. 6: From RB102. 7: *G. laurae* Goodrich, paratype. 8: *G. interioris* Goodrich, paratype.

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# PONTELLID COPEPOD DISTRIBUTION IN RELATION TO SURFACE WATER TYPES IN THE CENTRAL NORTH PACIFIC

by Kenneth Sherman

# PONTELLID COPEPOD DISTRIBUTION IN RELATION TO SURFACE WATER TYPES IN THE CENTRAL NORTH PACIFIC[1]

*Kenneth Sherman*
Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii

ABSTRACT

A study of the distribution of pontellid copepods collected from two central North Pacific water types, the North Pacific Central (NPC) and the North Pacific Equatorial (NPE), and from a zone of intermediate salinity between them, indicated that *Labidocera acutifrons*, immature *Labidocera* sp., and *Labidocera detruncata* were associated with the NPC water type, and may serve as useful indicators of the presence of this water during the summer months in the Hawaiian region. In winter *L. acutifrons* and *L. detruncata* were found to be more widely distributed than in summer in both the intermediate-salinity water and the NPE water type, suggesting a seasonal variation, which was thought to be related to a seasonal shift in water type distribution. Both sampling time and depth were shown to be important considerations in the collection of pontellid copepods. A comparison between plankton collections made at 2100 at the surface and from 0–60 m showed that pontellids were more numerous in the surface waters (0–1 m) than in lower levels at this hour.

## INTRODUCTION

Recent investigations at the U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, indicate that fluctuations in the availability of skipjack tuna, *Katsuwonus pelamis* (Linnaeus), may be related to movements of surface water types through the Hawaiian region (Seckel 1960a; Seckel and Waldron 1960; and Brown and Sherman 1962).

[1] The author wishes to express his thanks to Mr R. S. Glover, Oceanographic Laboratory, Scottish Marine Biological Association, for various suggestions and interest shown in the manuscript.

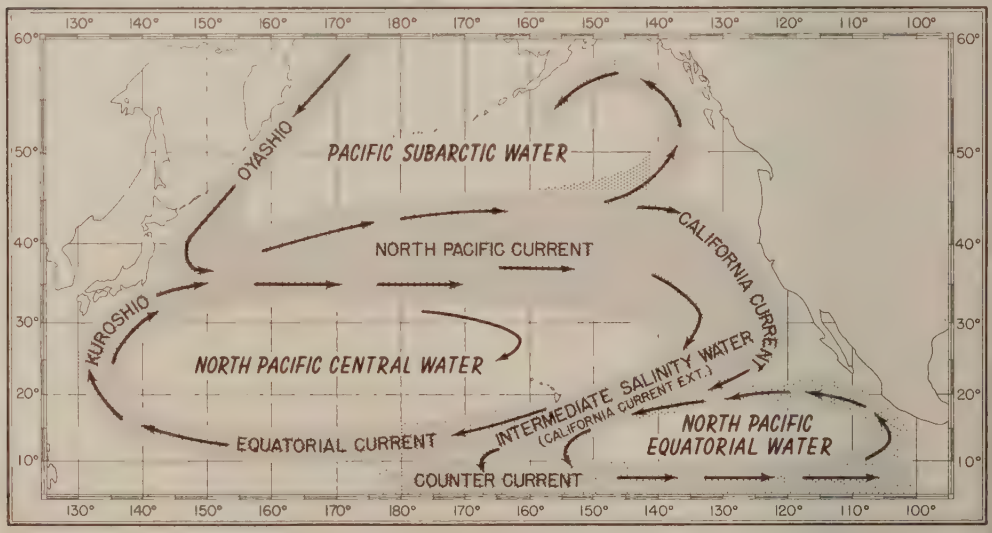


FIG. 1. Schematic chart of the major North Pacific water types and currents (modified from Seckel 1961; his "California Current Extension" is referred to in this study as the zone of intermediate-salinity water, 34.5–34.9‰).

TABLE 1. *Summary of pontellid sampling: Plankton tow characteristics, periods, time of day, and sources of previously published data*

| Vessel and cruise | Period | Type of analysis | Source of station data | Summary of tow characteristics | | | |
|---|---|---|---|---|---|---|---|
| | | | | Number | Type | Duration | Time of day |
| *Charles H. Gilbert* 53 | June–July 1961 | Horizontal distribution — day–night differences in distribution | Sherman and Brown, 1962 | 49 | Surface | 30 min | Day and night |
| *Hugh M. Smith* 46 | July 1958 | Meridional distribution—north of Hawaiian Islands | McGary and Graham, 1960 | 8 | Surface | 30 min | Day and night |
| *Hugh M. Smith* 40 | July–September 1957 | Meridional distribution—north and east of the Hawaiian Islands | Callaway and McGary, 1959 (Surface temperature and salinity data) | 46 | Surface | 30 min | Day and night[1] |
| *Hugh M. Smith* 2 | February–March 1950 | Meridional distribution—south of Hawaiian Islands | King and Demond, 1953; Cromwell, 1951 (surface temperature and salinity data) | 13 | Surface | 30 min | Day and night |
| *Charles H. Gilbert* 45 | July 1959 | Vertical distribution | Sherman and Brown, 1961 | 5 | Surface | 30 min | Night (2100 hr ZT) |
| | | | | 5 | 0–60 m | 30 min | Night (2100 hr ZT) |

[1] Only samples collected at 2100 hours ZT were used in surface distribution charts of pontellid occurrence.

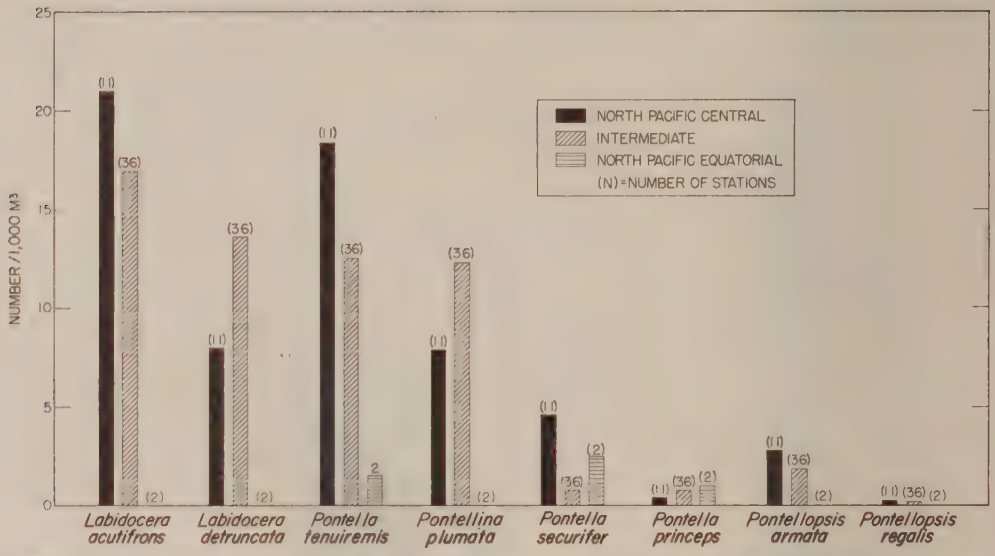


FIG. 2. Average numbers of several pontellid species present/1,000 m³ in the NPC water type, zone of intermediate water, and NPE water type. *Charles H. Gilbert* cruise 53, June–July 1961.

FIG. 3. Distribution of *Labidocera acutifrons* in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching indicates the areas occupied by the NPE (wide hatching) and NPC (narrow hatching) and the zone of intermediate-salinity water (intermediate hatching). Symbols indicate ranges of pontellid abundance in numbers per 1,000 m³. Calculated numbers of pontellids present per 1,000 m³ are given in parentheses.

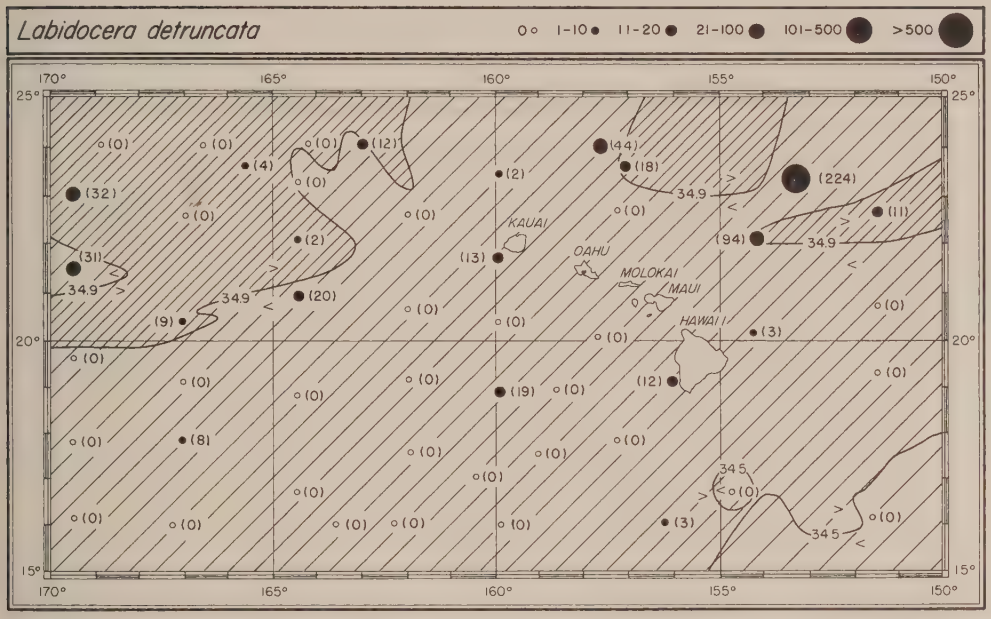


FIG. 4. Distribution of *Labidocera detruncata* in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching, parenthesized numbers, and symbols as in Figure 3.

Seckel (1960b) described three Pacific surface water types, the Subarctic Pacific (SP), North Pacific Central (NPC), and North Pacific Equatorial (NPE) (Fig. 1). He defined these as being approximately associated with the subsurface water masses as described by Sverdrup, Johnson, and Fleming (1942) but having different temperature and salinity structures, characterized by cold water and surface salinities of 33‰ or less (SP), warm with surface salinities of 35‰ or more (NPC), and warm with surface salinities of 34‰ or less (NPE). Brown and Sherman (1962), in a study of water type distribution in the vicinity of the Hawaiian Islands, modified the absolute values of Seckel's NPC and NPE water types in this region. They have shown that the movements of the NPC, NPE, and a zone of intermediate-salinity surface water (referred to by Seckel 1960b, as the California Current Extension), characterized by surface salinities of >34.9‰, <34.5‰, and 34.5–34.9‰ respectively, could be monitored seasonally using surface salinity. To supplement physical oceanographic data regarding the origin and seasonal movements of these water types, a study of pontellid copepod distribution was undertaken. Selection of these copepods was based on their great abundance in surface waters of the subtropical regions (Heinrich 1960), the relatively large size of the adults (3–4 mm), their bright blue pigmentation, and the ease of identification facilitated by the taxonomic works of Giesbrecht (1892) and Wilson (1950).

Previous studies of pontellid distribution in the central Pacific have shown that at least one species, *Labidocera acutifrons* (Dana), may serve as a useful water-type indicator. This species occurred at only two localities, the Hawaiian region and off the coast of Peru, in the Pacific-wide copepod occurrence data given by Wilson (1942). In addition, distribution of *L. acutifrons* west of the Hawaiian Islands along 170° W longitude was found restricted to water with salinities >35‰ by Heinrich (1960).

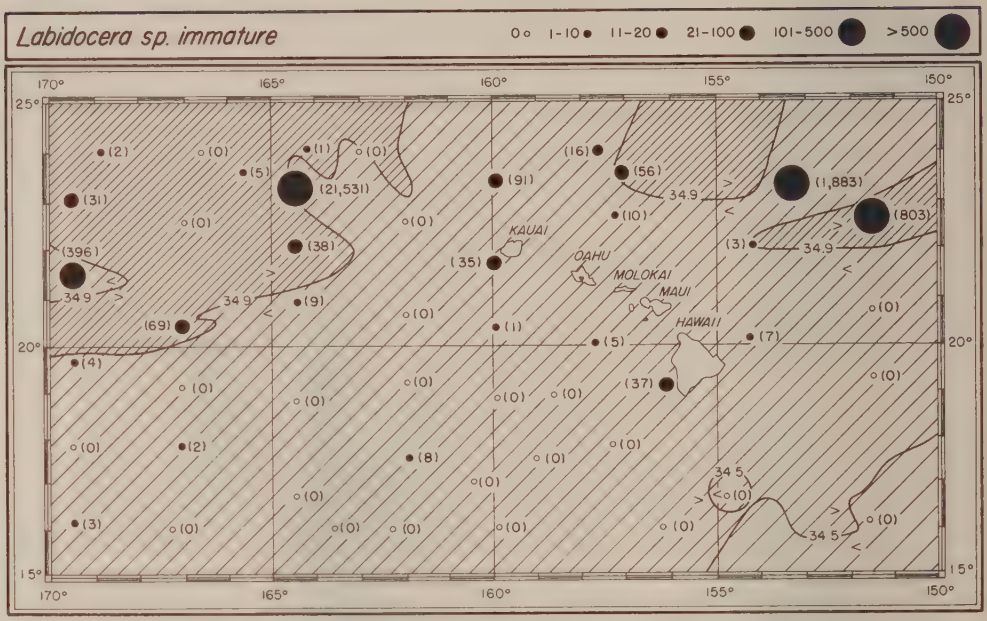


FIG. 5. Distribution of immature *Labidocera* sp. in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching, parenthesized numbers, and symbols as in Figure 3.

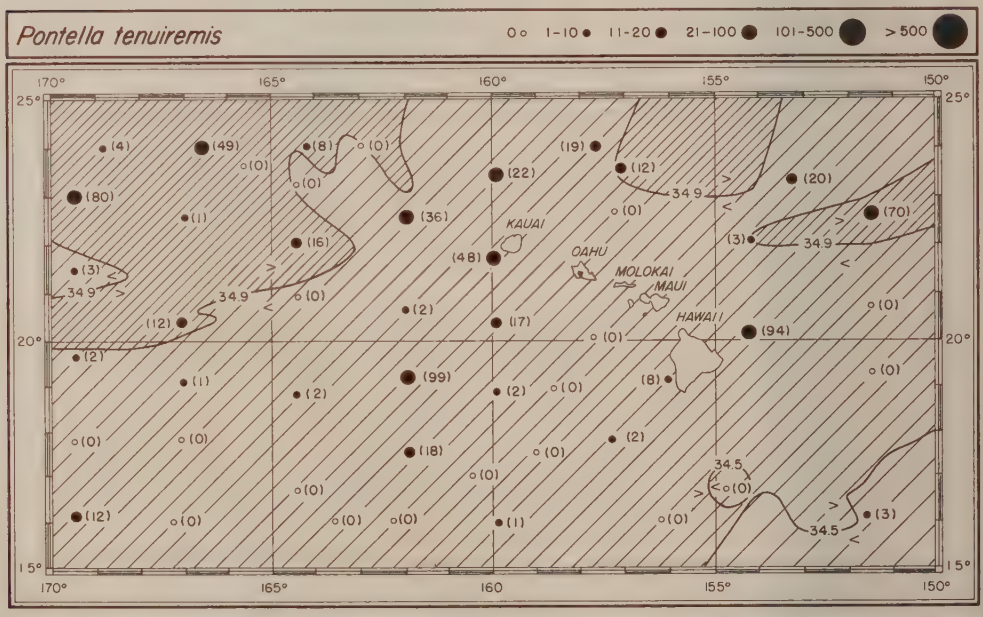


FIG. 6. Distribution of *Pontella tenuiremis* in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching, parenthesized numbers, and symbols as in Figure 3.

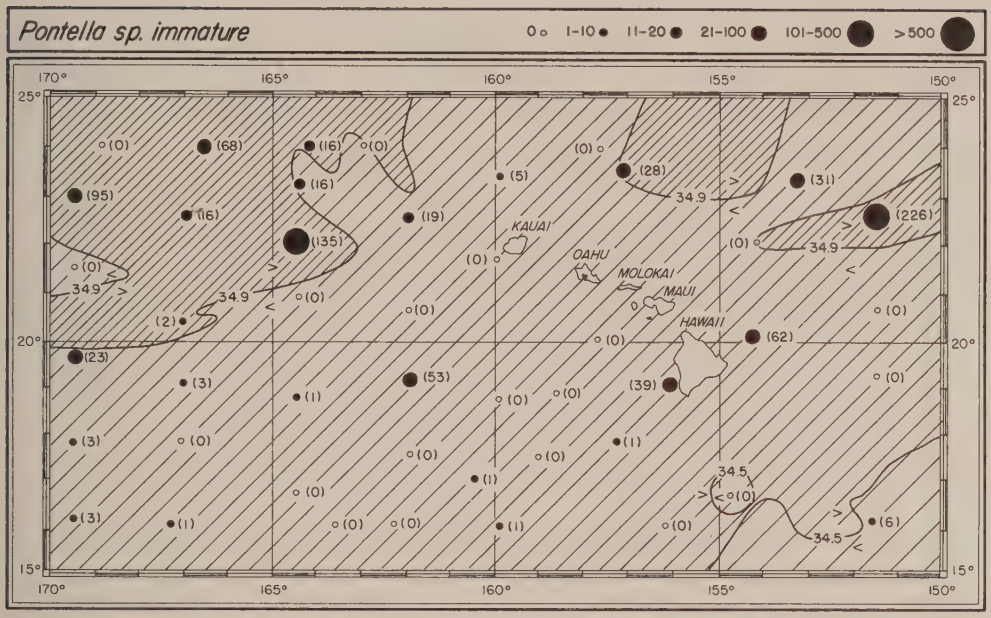


FIG. 7. Distribution of immature *Pontella* sp. in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching, parenthesized numbers, and symbols as in Figure 3.

## METHODS

Pontellids were separated from 126 plankton samples collected from central North Pacific waters during cruises of the U. S. Bureau of Commercial Fisheries vessels *Hugh M. Smith* and *Charles H. Gilbert*. Sampling periods, type of tows taken, and sources of previously published station data (dates, times, positions, temperatures, and salinities) are contained in Table 1. Plankton collections were made using a 1-m net (aperture width: 0.65 mm belly section; 0.3 mm rear section). All pontellids in the total, a half, quarter, or eighth aliquot, depending on the mass of the plankton sample and estimated numbers of pontellids present, were removed, sorted by species, and numbers of each species present per 1,000 $m^3$ of water strained were calculated.

## RESULTS

### *Relation of pontellid species to water types*

To assess the relation between pontellid distribution and water types, histograms were plotted of average numbers of each species collected from surface waters of the central Pacific during *Charles H. Gilbert* cruise 53, June–July 1961 (Fig. 2). This showed more pontellids in the NPC water and intermediate water than in the NPE water, except for two species, *Pontella securifer* Brady and *Pontella princeps* Dana. However, only two plankton collections were taken in the NPE water, thereby limiting the reliability of pontellid distribution presented on this basis.

The zone of intermediate-salinity water, where a number of samples were collected, is of a mixed character, with surface temperatures and salinity more closely related to the NPC water in the northern sector and in the southern sector more like the NPE water. Assuming that there is a similar mixture of the copepod faunas in this zone, with that in the northern sector more closely resembling the fauna of the adjacent NPC water and that of the southern sector more like the fauna of the NPE water, it would appear possible to gain a

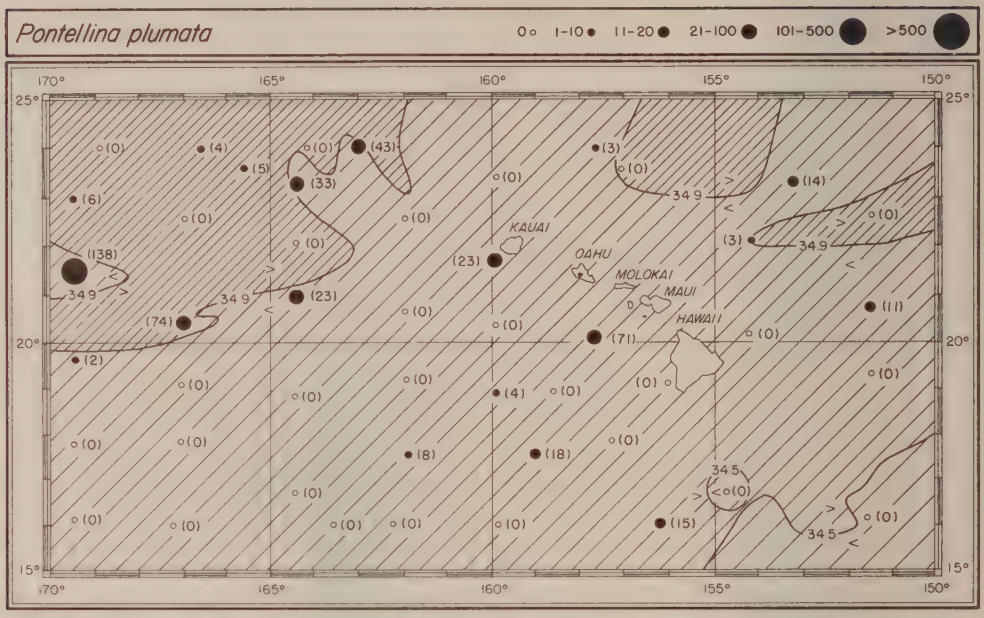


FIG. 8. Distribution of *Pontellina plumata* in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching, parenthesized numbers, and symbols as in Figure 3.

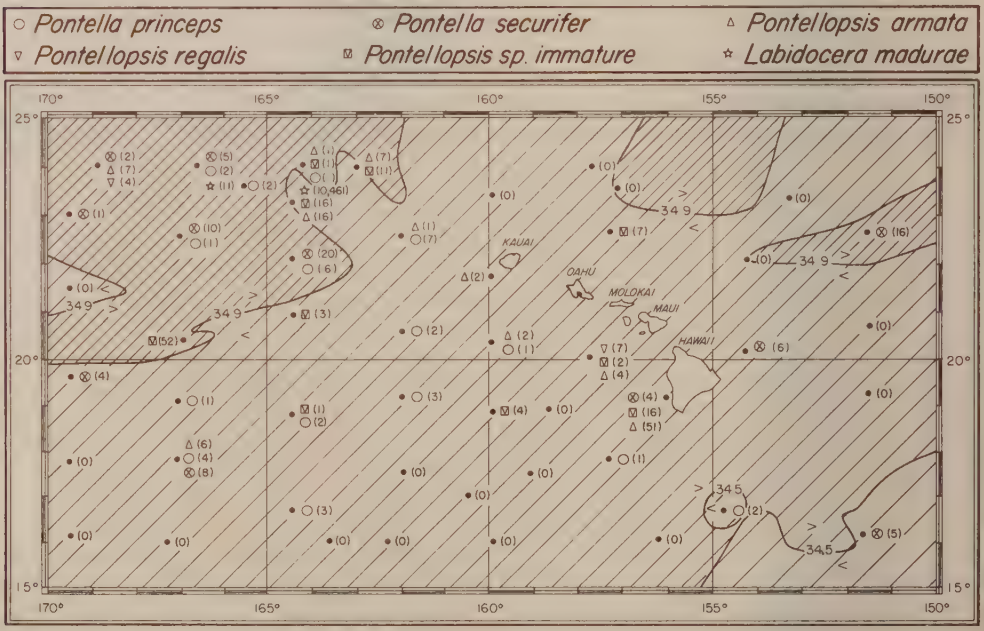


FIG. 9. Distributions of *Labidocera madurae, Pontellopsis armata, Pontella princeps, Pontella securifer*, immature *Pontellopsis* sp., and *Pontellopsis regalis* in relation to surface water types, *Charles H. Gilbert* cruise 53, June–July 1961. Hatching, parenthesized numbers, and symbols as in Figure 3.

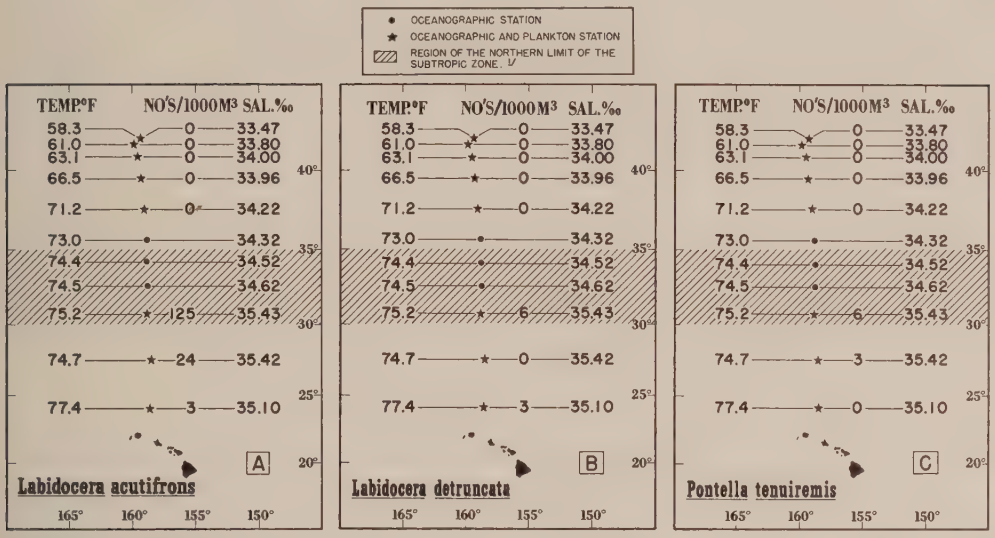


FIG. 10. Distributions of (A) *Labidocera acutifrons*, (B) *Labidocera detruncata*, and (C) *Pontella tenuiremis* in relation to salinity and temperature north of Hawaii, *Hugh M. Smith* cruise 46, July 1958. Pontellid occurrence is given in numbers per 1,000 $m^3$. [1] Modified from Hida (1957).

more reliable estimate of pontellid distribution, particularly in regard to the NPE water, by plotting horizontal distributions of pontellid occurrence directly onto surface salinity diagrams. This has been done in Figures 3–9, where hatching has been used to indicate areas occupied by the NPC, NPE, and intermediate-salinity waters.

The greatest concentrations of *Labidocera acutifrons*, *Labidocera detruncata* (Dana), and immature *Labidocera* spp. were found to be associated with the NPC water type present in the northern sector of the survey area (Figs. 3–5), suggesting that these species may serve as useful indicators of the NPC water type. Other species more numerous in the northern half of the survey area than in the southern half were *Pontella tenuiremis* Giesbrecht, immature *Pontella* sp., and *Pontellina plumata* (Dana) (Figs. 6–8). The continued presence, although in decreasing numbers, of these species southward from the NPC water type suggests that these species tolerate lower salinities than *L. acutifrons* or *L. detruncata*.

The highest number of pontellids in a single sample was found in shallow water (60 fathoms) near Necker Island (23°25′ N, 164°36′ W), where *Labidocera madurae* Scott reached 10,461/1,000 $m^3$. This species was found, however, only in this and in one other sample, taken 120 miles away to the west (23°52′ N, 166°33′ W). This species has previously been found abundant in areas adjacent to islands (Scott 1909; Sewell 1929; Mr E. C. Jones, *personal communication*), indicating that this aggregation was more closely associated with the island influence than with the NPC water type in which it was found. The immature *Labidocera* sp. collected in considerable numbers at these two stations were probably also *L. madurae*. The immature *Labidocera* spp. collected at other stations were probably *L. detruncata* and *L. acutifrons*, as those were the only mature members of the genus present.

The remaining species, *Pontellopsis armata* (Giesbrecht), *Pontella princeps*, *Pontella securifer*, and *Pontellopsis regalis* (Dana), were sparsely distributed throughout the survey area with no apparent rela-

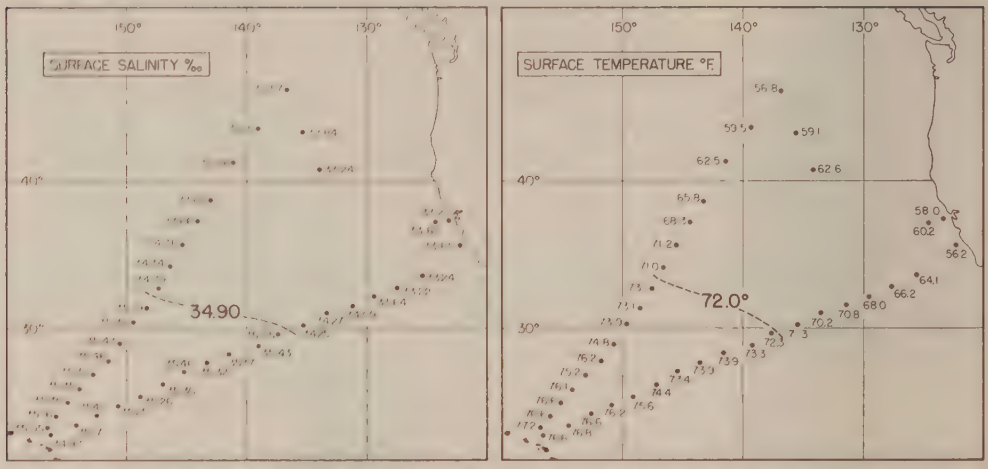


FIG. 11. Distribution of surface salinity and temperature, *Hugh M. Smith* cruise 40, July–September 1957.

tion to the central North Pacific water types (Fig. 9).

*Summer meridional distribution*

To gain an approximation of the northern and eastern limit of pontellid distribution, examination was made of 46 surface plankton samples collected on transects along longitude 158° W to the north of the Hawaiian Islands during *Hugh M. Smith* cruise 46 (July 1958) and northeast of the islands during *Hugh M. Smith* cruise 40 (July–September 1957) from Hawaii to the vicinity of the Oregon and California coasts. Species present were: *Labidocera acutifrons, Labidocera detruncata, Labidocera trispinosa* Esterly, immature *Labidocera* sp., *Pontella tenuiremis, Pontella securifer,* immature *Pontella* sp., *Pontellopsis regalis,* immature *Pontellopsis* sp., and *Pontellina plumata.*

FIG. 12. Distribution of *Labidocera acutifrons, Hugh M. Smith* cruise 40, July–September 1957.

On the northern transect, the numbers per 1,000 $m^3$ of *L. acutifrons, L. detruncata,* and *P. tenuiremis* tended to increase with increasing salinity and decreasing temperature to a salinity maximum in the northern boundary region of the NPC water type, located in the vicinity of latitude 32° N (Fig. 10). Unfortunately no plankton tows were taken at the adjacent three stations to the north. However, pontellids were absent from samples collected north of 36°24′ N, where surface salinities and temperatures dropped below 34.22‰ and 71.2°F, respectively (Fig. 10).

The distributions of surface salinity and temperature found on the northeast transects are shown in Figure 11. The pontellid distributions are shown in Figures 12 and 13 A–C. The most numerous was *L. acutifrons,* the maximal numbers of which were found in the NPC water type, which was bounded on the north and east by the 34.9‰ isohaline and the 72°F isotherm

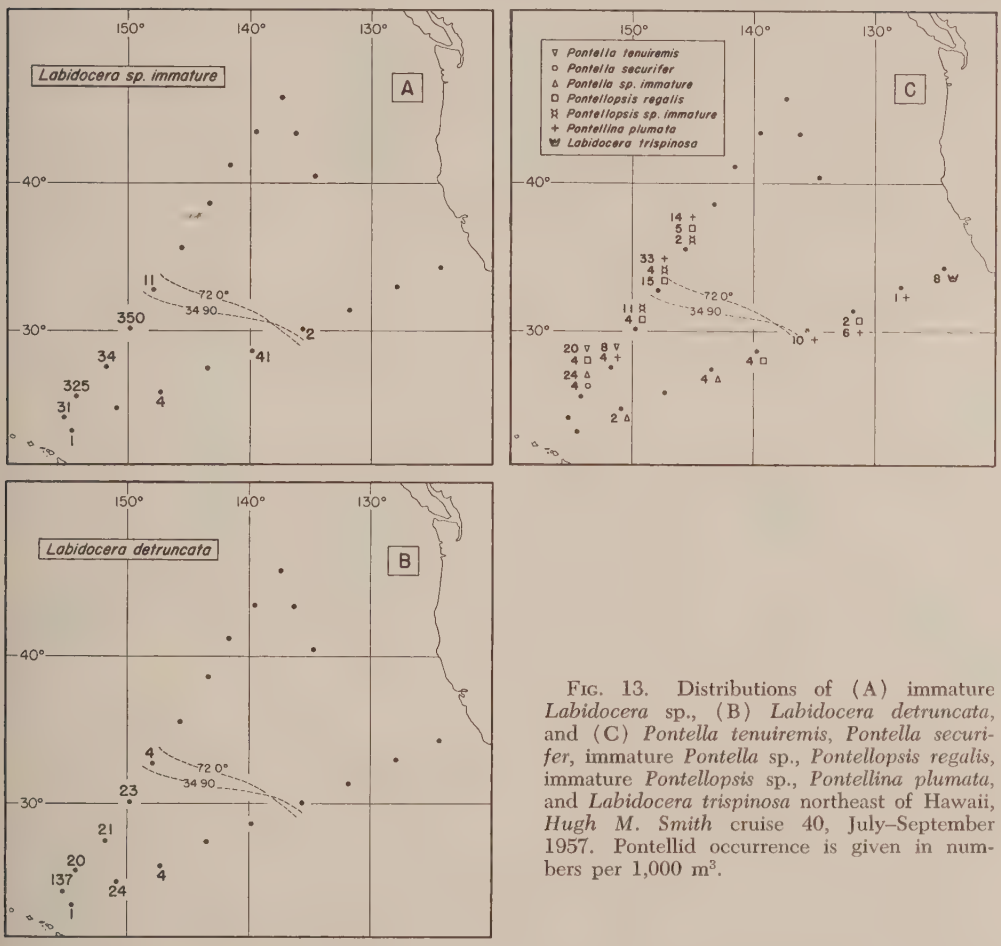


FIG. 13. Distributions of (A) immature *Labidocera* sp., (B) *Labidocera detruncata*, and (C) *Pontella tenuiremis*, *Pontella securifer*, immature *Pontella* sp., *Pontellopsis regalis*, immature *Pontellopsis* sp., *Pontellina plumata*, and *Labidocera trispinosa* northeast of Hawaii, *Hugh M. Smith* cruise 40, July–September 1957. Pontellid occurrence is given in numbers per 1,000 $m^3$.

(Fig. 12). Immature *Labidocera* sp., *L. detruncata*, immature *Pontella* sp., and *P. tenuiremis* were also found to be more numerous in the NPC water type than in adjacent waters; however, they were less abundant than *L. acutifrons*. The species *Pontellopsis* sp. and *Pontellina plumata* (Fig. 13 C) were distributed in both the NPC water type and adjacent water of lower salinity (34.9–33.22‰) but were not numerous in either region (<41/1,000 $m^3$/station).

No pontellids were found in the Subarctic Pacific water type (salinities <33‰). The remaining pontellid, *L. trispinosa*, was found at a single station close to the California coastal region where the species was first observed by Esterly (1905).

Previous investigators have reported the occurrence of *L. acutifrons*, *L. detruncata*, and *P. tenuiremis* from tropical and subtropical waters (Brady 1883; Dana 1853; Giesbrecht 1892; Scott 1909; Sewell 1929; Wilson 1942, 1950; and Heinrich 1960). In this regard, the location of the northern limit of abundance of these species is not unexpected, since Hida (1957) and McGary, Jones, and Graham (1957), using both physical and biological data, have reported the northern limit of their "Subtropic" and the southern boundary of their "Transition Zone" fauna to be located be-

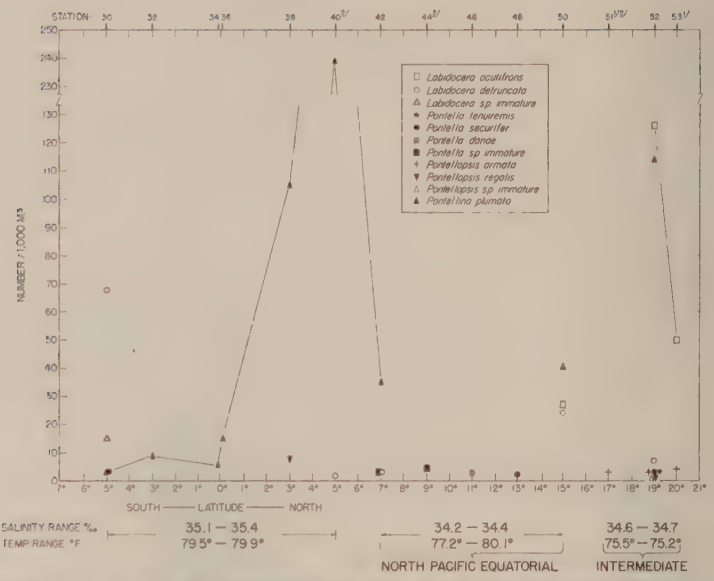


FIG. 14. Distributions of several pontellid species south of the Hawaiian Islands along longitude 158° W, *Hugh M. Smith* cruise 2, February–March 1950. [1] Large mesh samples, therefore numbers of pontellids present are minimal estimates of abundance. [2] Tows taken during daylight hours, therefore numbers of pontellids present are minimal estimates of abundance.

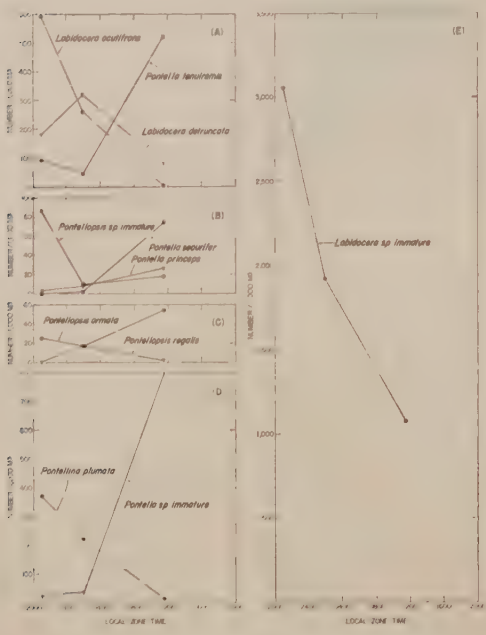


FIG. 15. Day–night variation in pontellid copepod abundance, *Charles H. Gilbert* cruise 53, June–July 1961.

tween latitudes 33° and 34° N in the region north of Hawaii during the summer months.

### *Winter meridional distribution*

Examination was made of 13 surface plankton samples collected on a meridional transect south of the Hawaiian Islands from 20° N to 5° S along longitude 158° W during *Hugh M. Smith* cruise 2 (February–March 1950) to provide an estimate of the southern limit of pontellid abundance. During this period of sampling the western boundary of the NPE was located between 158° W and 172° W as indicated by the values of surface temperature and salinity. Species present in greatest numbers were *L. acutifrons*, *L. detruncata*, and *P. plumata* (Fig. 14). The southernmost occurrence of *L. acutifrons* was 14°57′ N, in a boundary region between the intermediate-salinity water and NPE water type. *L. detruncata* and *P. plumata* were found along the entire transect; however, they

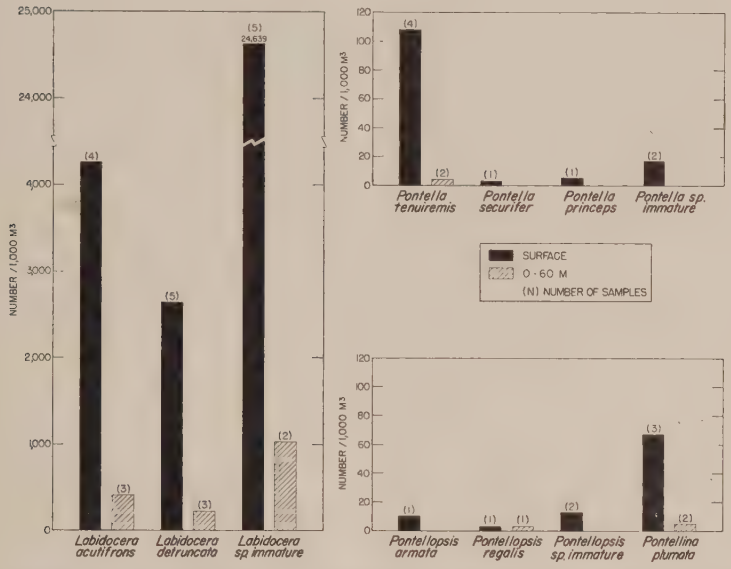


FIG. 16. Variation between numbers of pontellids found in five pairs of simultaneous surface and 0–60 m tows.

were less numerous in the NPE water type. The remaining species, *P. tenuiremis*, *P. securifer*, *P. danae* Giesbrecht, immature *Pontella* sp., immature *Labidocera* sp., *P. regalis*, *P. armata*, and immature *Pontellopsis* sp., were present at various locations along the transect but were not very numerous (<15/1,000 $m^3$) at any single station or in any water type (Fig. 14).

### *Day–night and vertical distribution*

An estimate of pontellid day–night distribution was made by comparing the species abundance of pontellids in 49 surface plankton samples collected during *Charles H. Gilbert* cruise 53, June–July 1961. Samples were collected between the hours of 1100–1200, 2000–2100, and 0100–0300 (local zone time). Species most abundant during the daylight period (1100–1200) were *P. tenuiremis*, *P. securifer*, *P. princeps*, immature *Pontella* sp., and *P. armata*. During the night (2000–0300) *P. plumata*, *L. acutifrons*, *L. detruncata*, immature *Labidocera* sp., *P. regalis*, and immature *Pontellopsis* sp. were present in greatest numbers (Fig. 15).

Previous investigations have shown that pontellid species are more abundant in surface waters of 0–50 m (Wilson 1942) and 0–30 cm (Heinrich 1960) than in deeper levels. A single species, *P. plumata*, was reported by Heinrich (*ibid.*) to be most abundant in the sub-surface waters between 50 and 100 m during daylight and between 0 and 25 m during darkness. To gain an additional measure of the vertical distribution of pontellid species which would indicate optimal sampling depths, examination was made of simultaneous pairs of surface and 0–60 m open oblique hauls made at 2100 at 5 stations in the NPC water type and the intermediate-salinity water during *Charles H. Gilbert* cruise 45, July 1959. All pontellid species present, with the exception of *P. regalis*, were found to be more numerous in the surface waters (Fig. 16).

## DISCUSSION

A differential occurrence of pontellid species was found in the central Pacific

waters during the summers of 1961 and 1957 (Figs. 3–8, 12, and 13 A–C). The close association found between *L. acutifrons*, *L. detruncata*, and immature *Labidocera* sp. and the NPC water type (Figs. 3–5, 12, and 13 A, B) suggests that these species may be useful for indicating the presence of the NPC water type during the summer months in the Hawaiian region.

The southward decrease in numbers of *P. tenuiremis*, immature *Pontella* sp., and *P. plumata* during 1961 suggests that maximal numbers of these species are found in the NPC and the boundary region between the NPC and intermediate-salinity water (Figs. 6–8). These species appear to have the ability to endure salinities ranging from 35‰ to 34.5‰. The decrease in numbers of these species in, and adjacent to, the NPE water type suggests either that salinities <34‰ are not optimal for reproduction and growth, or that the relatively wide band of intermediate-salinity water present during the 1961 summer survey period was too great for dispersal to the NPE from an area of maximum abundance to the north, thereby serving as an effective physical barrier to southern distribution. During the winter months, when the intermediate-salinity water is restricted to a narrow band and the NPC and NPE water types are closer in the Hawaiian region, greater mixing between the NPC and NPE and their associated biota would be expected to occur. Examination of pontellid distribution (Fig. 14) during the winter months (February–March 1950) showed that *L. acutifrons*, *L. detruncata*, and *P. plumata* were more widely distributed in the intermediate-salinity and NPE water than during the summer period (June–July 1961, Figs. 3–5). Although the data used in this comparison were not collected during the same year, the seasonal variation in pontellid distributions lends support to the probability of an increased winter mixing of pontellids between water types.

From the data presented in Figure 16, it is apparent that pontellids are more abundant in the upper surface waters (0–1 m) than in depths of 0–60 m. This, when considered with the day–night variation shown in Figure 15, indicates that careful consideration should be given to the selection of the most opportune sampling time and depth for collecting various pontellid species.

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readable scales examined depicted the same age. However, on the basis of evidence from one fish only limited conclusions regarding this problem can be made. A more extensive study into this problem is planned using more specimens.

*Absorption and age determinations.* The majority of the scales sampled from chum salmon caught in streams and estuaries show evidence of absorption (loss of scale material) at the margin of the scale. When these scales are used to determine the age of the fish the reader must attempt to estimate the amount of absorption that has occurred. This estimate is generally based on the degree to which the margin of the scale differs in appearance from the normal. In other words, has the loss of scale material from the edge of the scale been great enough to remove one or more annuli? Generally no scientifically established method of measuring absorption is available.

It appears that errors of one or more years can be made when using partially absorbed scales for age determination. Further study of the effect of scale absorption on age determinations and of the possibility of using otoliths and other methods to supplement current procedures is in progress.


## Summary

Differences in meristic characters have enabled us to identify the continental origin of chums taken at sea with the exception of those originating from the Bering Sea coast and Kodiak Island region. Scale characteristics are being examined for possible differences which can be used to supplement meristic characters.

This report places particular emphasis on the methods and assumptions required in the use of chum salmon scale characteristics for population differentiation and age determination studies.

A method of establishing a line of count and measurement that is consistent and also accounts for scale shape is described. Circuli counts and scale lengths differ with change in position of line of count or measurement on the scale.

Regeneration of scales may be difficult to detect in some cases, especially in the central area of the scale. Variation of scale characteristics with change in scale sampling area on the body is of sufficient magnitude to be a serious source of error in a study designed to separate Asian and North American chum salmon. The quality of the plastic scale impressions may affect the validity of scale racial data. Proof of the validity of age determinations made from chum salmon scales is given by agreement of scale age determinations with the known age of marked fish. Lack of knowledge of the time of annulus formation can result in errors of unknown magnitude in age determinations of chum salmon, especially those taken early in the season.

Age readings of 610 scales sampled from a single chum salmon specimen gave limited evidence supporting the assumption that all readable scales on chum salmon have the same number of annuli regardless of body position of the scale.

Age reading of partially absorbed scales are subject to errors of unknown magnitude. Studies designed to solve these problems are in progress.


# KING CRAB STUDIES

by Herbert Shippen and Takashi Miyahara

The year 1961 saw continuation of rapidly increasing fishing pressures on eastern Bering Sea king crabs. In 1960 one Russian and two Japanese motherships were operated; in 1961 two Russian and five Japanese motherships took part in the fishery.

By utilizing available catch statistics and announced production targets, we can estimate the catch of Japanese king crab operations in the eastern Bering Sea in 1961 to be about 3.5 million male crabs. For the two Russian mothership expeditions we can only guess that a combined total of about two million crabs may have been taken. The estimated 5.5 million crabs removed by these two nations is probably conservative and represents at least a fourfold increase in the catch of king crab in the eastern Bering Sea in comparison with the level of fishing during the period from 1953 to 1958 (Fig. 35).

In addition to expansion of king crab fishing by Japan and Russia, there have also been increases in groundfish operations. Although these fleets are

International North Pacific Fisheries Commission, Annual Report 1961, Vancouver, Canada, 1963, p. 124-127.

## Age Determination from Chum Salmon Scales

### Assumptions

The soundness of the method of using chum salmon scales for age determinations depends on the validity of the following basic assumptions:

1. Recognizable markings occur on the scale annually.
2. The annulus is formed during a particular period of time common to the species or the time of annulus formation is known for the individual specimens.
3. The position on the fish from which the scale is sampled has no effect on age determination.
4. Errors in age determinations made from scales showing signs of absorption (loss of scale material) at the scale margin are negligible.

*Annulus and age of fish.* The assumption that there are recognizable age marks or annuli present on the scales of chum salmon has been subjected to only limited critical examination.

Absolute proof of the validity of the assumption can be obtained from scales of authentic marked fish of known age. For example, the scale of a chum salmon marked as a young fry and recovered after spending three winters at sea should have three recognizable annuli present. In a preliminary attempt to test the assumption, 96 scales from known age chum salmon were examined by two experienced chum salmon scale readers. The scales were generously provided by the Washington State Department of Fisheries and the Fisheries Research Board of Canada. All scales were sampled from chums that were fin marked as wild fry and recovered as adults.

In most cases the known age of the chum salmon and the age as determined from the scales was the same. Reader 1 rejected eight of the 96 scales because of regeneration scars. Of the 88 scales read by reader 1, only one was aged incorrectly. Reader 2 rejected 15 scales because of regeneration and excessive absorption. Reader 2 incorrectly aged three of the 81 scales he deemed acceptable for age determination.

Scales from other areas and years may be more or less difficult to interpret and other scales from marked chum salmon should be examined. Nevertheless, this test gives strong support to the assumption that there are recognizable age marks (annuli) on chum salmon scales.

*Time of annulus formation.* It has generally been assumed that an annulus or band of narrow closely spaced circuli is formed on a chum scale in the winter due to a period of slow growth or complete cessation of growth. With the approach of spring it was assumed that new growth occurs and varying numbers of thick, widely-spaced circuli should be formed beyond the annulus by spring. The growth that occurs by spring should be somewhat less than the total growth that occurs for the entire growing season which is assumed to be from early spring to late fall. However, scale examiners have observed scales from chum salmon caught on the high seas in May that have a very large amount of growth at the edge of the scale. This presents a problem when attempting to determine the age of the fish from the scale. Is this large amount of growth "too much" to have occurred by May? If so, then it must be assumed that the growth at the edge of the scale is of the previous year and the annulus must not have formed as yet. If the examiner feels this is true he must add one year (one annulus) to the observed number. At present there is no scientifically established criteria for determining whether this growth is "too much" and errors of one year can occur when determining the age of high seas chums caught early in the year. Knowledge of the time or variation in time of annulus formation would aid in reducing this source of error. Attempts are being made to obtain scales sampled through the year and other data on scale growth are being assembled to obtain further information regarding this problem.

*Scale body position and age determination.* Generally an attempt is made to sample scales from a particular location on the body of the chum salmon for age determination. However, in many cases scales are missing or unreadable scales are found at the designated location and scales must be sampled from other body positions.

It is possible that all of the scales on a chum salmon are not formed early in life or there may be variation in scale growth such that all scales do not depict the same age. It is therefore important to test the validity of the assumption that all scales on a chum salmon depict the same age.

A random sample of 610 scales was taken from a single chum salmon specimen. The scales were randomly intermixed with other chum scales to eliminate bias when determining the age. A

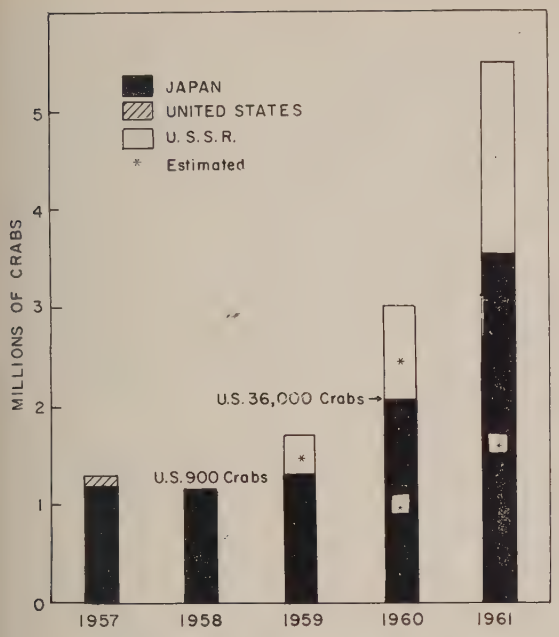


FIGURE 35. Commercial catch of adult male king crabs in eastern Bering Sea, 1957–1961.

primarily harvesting fish, we expect that substantial numbers of king crabs are also taken. Requests for catch data of all fishing operations in this area have been made to the governments of Japan and the Soviet Union.

United States' king crab research activities in the eastern Bering Sea were conducted from the 80-foot research trawler *Paragon* during July. The vessel was chartered by the Bureau of Commerical Fisheries, and after initially being used in salmon studies, spent four weeks in the Bering Sea sampling king crabs. Sixty stations were successfully completed where 3,775 male and 1,608 female crabs were sampled and measured; 2,790 male crabs were tagged and released —twice as many as we were able to tag last year.

In addition to tagging for growth, migration and mortality studies, meat content, ecological and oceanographic data were collected. Two research objectives which we had hoped to achieve during the 1961 charter period were, however, only partially completed due to the lack of vessel charter time. One of these objectives was to define the extent of distribution of adult male king crabs in the eastern Bering Sea by means of systematic sampling on the 20-mile grid pattern which we have used in past years. In order to obtain reliable estimates of population abundance and to insure random distribution of tagged crabs throughout the populations, it was necessary that the station pattern be extended sufficiently to include the area occupied by the stock. Preliminary examination of the 1961 station pattern catches indicates that crabs were probably distributed well beyond the area surveyed.

A second phase in which we fell short of the measure of success for which we had hoped was in the release of double-tagged crabs. The purpose of this experiment was to ascertain the rate at which tagged crabs die as a result of the tagging operation and the proportion of tagged crabs which lose their tags in the interval between tagging and time of molting. This knowledge is necessary for precise determination of the natural death rate of crabs, proportion of the population taken by the fishery, and the fraction of the stock which survives to the next year. We estimated that approximately 2,000 male crabs must be tagged in this experiment in order to assure significant return, but we were able to tag only 350. It is apparent that this experiment will require considerably more vessel time than we are presently able to allocate in view of the demands of other research problems.

Two Russian king crab mothership operations were observed northwest of Amak Island. This area is somewhat farther west than commercial operations have been observed in the past and is usually an area of concentration for recently molted crabs that have been found to contain less meat than old-shelled crabs. However, the 1961 samples showed a slightly higher proportion of old-shelled crabs in this area than in past years.

During 1961, we received tags from 539 crabs recovered by fishing operations in the eastern Bering Sea during 1960 and 1961. In August, 415 king crab tags recovered aboard the mothership *Tokei-maru* were returned to us from Japan. Tags from two king crabs recovered by a United States fishing vessel in 1960 near Unalaska Island were returned in June. In February, 122 tags were returned from king crabs recovered by the Russian mothership, *Vsevolod Sibertsev* during 1960 operations. Table 17 gives a summary of our king crab releases and returns to date.

In addition to returns noted in Table 17, we are quite certain that recoveries have been made by the *Shinyo-maru* operations in 1960 and 1961. These recoveries have not as yet been transmitted to us. Russian recoveries for 1961 have not yet been received. Further, tagged king crabs must have been taken by

TABLE 17. Summary of tag releases and returns*.

| Tagging year | Number tagged | Returns during 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| 1954 | 1,107 | 44 | 60 | 1 | 2 | 1 | 0 | 0 | 0 | 108 |
| 1955 | 1,351 | | 32 | 53 | 35 | 18 | 12 | 6 | 2 | 158 |
| 1956 | 4,063 | | | 53 | 197 | 114 | 67 | 49 | 37 | 517 |
| 1957 | 13,795 | | | | 39 | 192 | 235 | 182 | 151 | 799 |
| 1958 | 9,851 | | | | | 40 | 118 | 123 | 120 | 401 |
| 1959 | 4,447 | | | | | | 41 | 77 | 81 | 199 |
| 1960 | 1,327 | | | | | | | | 24 | 24 |
| 1961 | 2,790 | | | | | | | | | |
| TOTAL | | 44 | 92 | 107 | 273 | 365 | 473 | 437 | 415 | 2,206 |

* The table is presented to show the magnitude of release and returns. Since each year's tagging experiment varied in sex, size, and area, and the recovery is the result of varying fishing intensity, the data are not strictly comparable.

Japanese and Russian groundfish fleets in the past several years but these have not yet been returned. Requests for the tags and recovery information have been made to the government agencies.

One of our studies utilizing data from king crab tag returns is that of the growth of adult male king crabs. At present the report is in the hands of the printers and is expected to be published in the near future. The completion of this phase of our work is a notable step since the yield of a stock is dependent upon growth.

The relationship of meat content to size and molting stage is closely related to the study of crab growth. This project was emphasized during the 1961 vessel charter period, and a large number of field observations was collected to fill in gaps and to extend the range of data from previous years.

A report on the movements of crabs as determined from tag releases and recoveries is being prepared for publication. A description of the methods employed in this study and a general summary of the results appeared in the Annual Report for 1960.

A major objective of our investigations is to determine the distribution of the king crab population in the eastern Bering Sea, to estimate crab abundance, and to arrive at some judgment as to the accuracy of our abundance estimate. Because of the problems of sampling, it has long been apparent that it was not feasible to attempt to assess the entire king crab population which consists of countless millions of planktonic individuals as well as the more finite numbers of older crabs. We must, therefore, define

TABLE 18. Eastern Bering Sea king crab abundance estimates 1957–1960. (Survey totals only, no additions from commercial catch prior to survey or other adjustment of survey totals.)

| Year of survey | Date | Length (mm.) | Number of males: New and soft shell | Old and very old | TOTAL | Number of females |
|---|---|---|---|---|---|---|
| 1957 | June 25–July 25 | <132.5 | 19,105,000 | 6,336,000 | 25,441,000 | |
| | | >132.5 | 5,375,000 | 7,782,000 | 13,157,000 | |
| | | TOTAL | 24,480,000 | 14,118,000 | 38,598,000 | 35,081,000 |
| 1958 (1) | April 29–June 3 | <132.5 | 15,049,000 | 1,191,000 | 16,240,000 | |
| | | >132.5 | 15,462,000 | 6,767,000 | 22,229,000 | |
| | | TOTAL | 30,511,000 | 7,958,000 | 38,469,000 | 20,908,000 |
| 1958 (2) | June 8–July 11 | <132.5 | 20,685,000 | 1,384,000 | 22,069,000 | |
| | | >132.5 | 10,646,000 | 6,790,000 | 17,436,000 | |
| | | TOTAL | 31,331,000 | 8,174,000 | 39,505,000 | 43,987,000 |
| 1959 | May 2–19 | <132.5 | 10,544,000 | 341,000 | 10,885,000 | |
| | | >132.5 | 18,184,000 | 6,961,000 | 25,145,000 | |
| | | TOTAL | 28,728,000 | 7,302,000 | 36,030,000 | 20,284,000 |
| 1960 | August 2–30 | <132.5 | 7,999,000 | 750,000 | 8,749,000 | |
| | | >132.5 | 3,170,000 | 5,775,000 | 8,945,000 | |
| | | TOTAL | 11,169,000 | 6,525,000 | 17,694,000 | 18,439,480 |

the population with which we are dealing as the adult crabs of the eastern Bering Sea which are accessible by otter trawl at the time of sampling. Our sampling has been restricted primarily to the broad shelf which is the locality of commercial crabbing operations. Because of migrations and other movements, the composition of the crab population on this shelf appears to be quite variable so that the results of sampling, both with regard to distribution and abundance, should be considered relative to the time of year when samples were taken. The effects of the removal of large numbers of crabs by the fishery prior to the time of the sampling must also be considered in comparing one year with another.

Abundance estimates for each station pattern survey were made by expanding the catch at each station in relation to the area of ocean bottom swept by the otter trawl. In 1958 two surveys were made; in 1957, 1959, and 1960 only one. Abundance estimates based on these surveys are given in Table 18.

In Figure 36 the abundance estimates for various groups of crabs have been arranged in time sequence by the midpoint of the survey period. This arrangement suggests that for females and new-shelled males a large part of the variation between years may be due to seasonal movement into and out of the sampling area rather than to actual differences in abundance in the eastern Bering Sea. However, for the large old-shell males the number in the sampling area appears to be relatively constant during the season of sampling, suggesting that there may be no significant migration of these crabs during the late spring and summer months. This is of particular significance since these large old-shell males are the crabs generally selected by the fisheries.

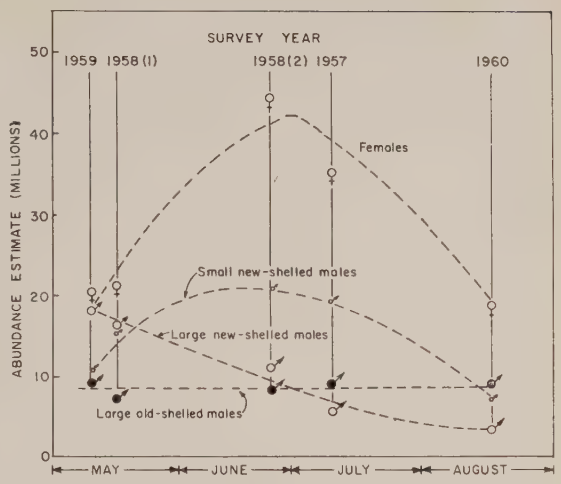


FIGURE 36. Bering Sea king crab abundance estimates, 1957–1960. (Large old-shelled estimates have been adjusted to compensate for commercial catches prior to the survey and for incomplete coverage of the station pattern in 1959.)

We have begun to make estimates of the level of yield which may be taken on a sustained basis from the eastern Bering Sea king crab stock. We believe that our present knowledge of the fishery and the population upon which it is based is sufficient for such calculations to be made. However, most of the factors which enter into yield calculations were determined for a period when the level of fishing was much less than we are experiencing at present.

Since it is probable that some of these factors may change as a result of the large increase in fishing during recent years, continued observations of the effects of the fishery upon the stocks are necessary.

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Experience Paper No. 10

# MONOFILAMENT GILL NET FISHING FOR SKIPJACK TUNA IN HAWAIIAN WATERS (A PROGRESS REPORT)

By

RICHARD S. SHOMURA
U. S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

## Abstract

The Hawaiian skipjack fishery is showing signs of a decline. This is especially evident in the size of the fleet, which has decreased 40 percent since 1948. The problem is one of a static level of fishing efficiency of the pole-and-line method and increasing operational costs. The solution requires increasing the catch without a proportionate increase in cost.

The present study was carried out on a chartered skipjack boat from July 23 to September 29, 1961. The method of fishing was to locate a skipjack school, chum the school to the stern of the boat using live bait, set the net from a wooden bin while the boat moved ahead at chumming speed, carry out pole-and-line fishing, and haul in the net with a powerblock.

The method of net fishing which we have developed has not been tried elsewhere, therefore the field work was devoted to working out operational problems and evaluating different methods of fishing the gear. Although we were able to catch skipjack with the monofilament gill nets, the catches were not large enough to indicate that gill nets will replace the pole-and-line method. There were, however, indications that the nets can be used to effectively supplement the pole-and-line catches.

Recommendations are presented which should provide for a compatible combination of the two methods of fishing. We hope to resume field work during next year's skipjack fishing season.

EP/10

# UTILISATION DU FILET MAILLANT EN MONOFILAMENTS SYNTHETIQUES POUR LA PECHE DE LA BONITE A VENTRE RAYE DANS LES EAUX HAWAIENNES (RAPPORT SUR L'ETAT DES TRAVAUX)


## Résumé

La pêche à la bonite à ventre rayé est en régression à Hawai, comme le montre notamment l'importance de la flotte de pêche, qui a diminué de 40 pour cent depuis 1948. Ce déclin est dû au fait que le rendement de la méthode de pêche à la canne et à l'hameçon est demeuré stationnaire, tandis que les frais d'exploitation ont augmenté. Le problème consiste à augmenter les quantités pêchées sans entraîner un accroissement proportionnel des coûts.

La présente étude a été faite du 23 juillet au 29 septembre 1961 à bord d'un thonier loué pour la circonstance. La méthode adoptée consistait à repérer un banc de bonites à ventre rayé, à les attirer vers l'arrière du bateau en leur jetant de l'appât vivant, à mettre à l'eau le filet lové dans une cuve de bois tandis que le bateau avançait à l'allure d'appâtage, à pêcher à la canne et à l'hameçon, et à rentrer le filet avec un treuil à moteur.

La méthode de pêche au filet que nous avons mise au point n'ayant jamais été tentée ailleurs, le travail a consisté à résoudre les problèmes opérationnels et à comparer différentes techniques d'utilisation du filet. Bien que nous ayons réussi à capturer des bonites à ventre rayé avec les filets maillants en monofilaments synthétiques, les résultats n'ont pas été suffisants pour conclure que ces filets permettraient de constituer un appoint efficace à la pêche avec canne et hameçon.

Des recommandations sont formulées sur la façon de combiner les deux méthodes de pêche. Nous espérons reprendre les travaux pratiques au cours de la prochaine campagne de pêche à la bonite à ventre rayé.


# PESCA DEL BARRILETE EN AGUAS HAWAIANAS CON TRASMALLO MONOFILAMENTO (INFORME SOBRE LA MARCHA DE LOS TRABAJOS)


## Extracto

La pesquería hawaiana del barrilete muestra síntomas de disminución, lo cual se evidencia singularmente en las proporciones de la flota, reducida al 40 por 100 después del 1948. El problema está en el nivel estático del rendimiento pesquero del curricán y el creciente costo de las operaciones. Su solución requiere un aumento en las capturas sin un incremento proporcional de costos.

El presente estudio fue efectuado a bordo de un atunero fletado especialmente para la pesca del barrilete, desde el 23 de julio hasta el 29 de septiembre de 1961. Consistía el método de pesca en localizar el cardumen; atraerlo hacia la popa de la embarcación con

cabo vivo; calar la red por su caja, avanzando el barco mientras seguía arrojándose cebo al mar; pescar con caña y sedal y cobrar la red con un cuadernal mecánico.

El método de pesca con red ideado por nosotros no ha sido ensayado en parte alguna; por consiguiente, nuestro trabajo experimental consistía en el planteamiento de problemas funcionales y en la evaluación de diferentes métodos de pesca con arte. Si bien pudimos capturar barriletes con trasmallo monofilamento, las capturas no fueron lo suficientemente abundantes para afirmar que estas redes pueden servir de eficaz complemento de la caña y sedal.

Se formulan recomendaciones que ofrecen una compatible combinación de ambos métodos de pesca. Esperamos poder reanudar el trabajo de campo durante la campaña de pesca del barrilete del año próximo.

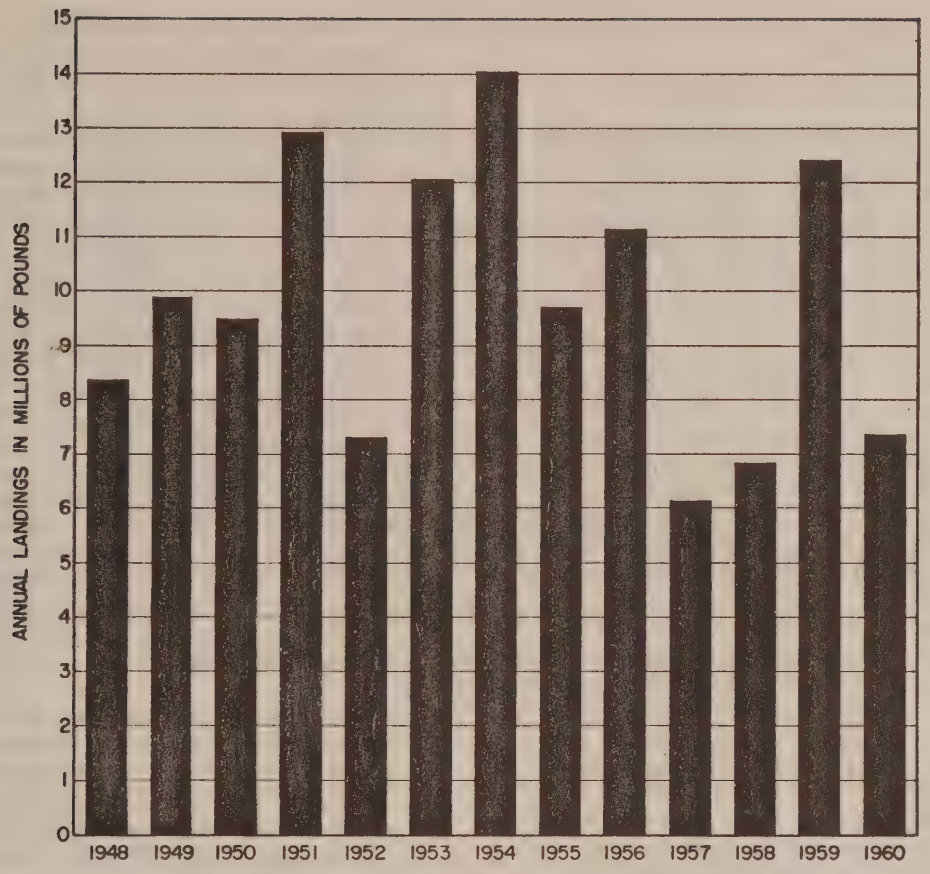


Fig. 1 Annual landings of Hawaiian skipjack fishery; 1948-1960

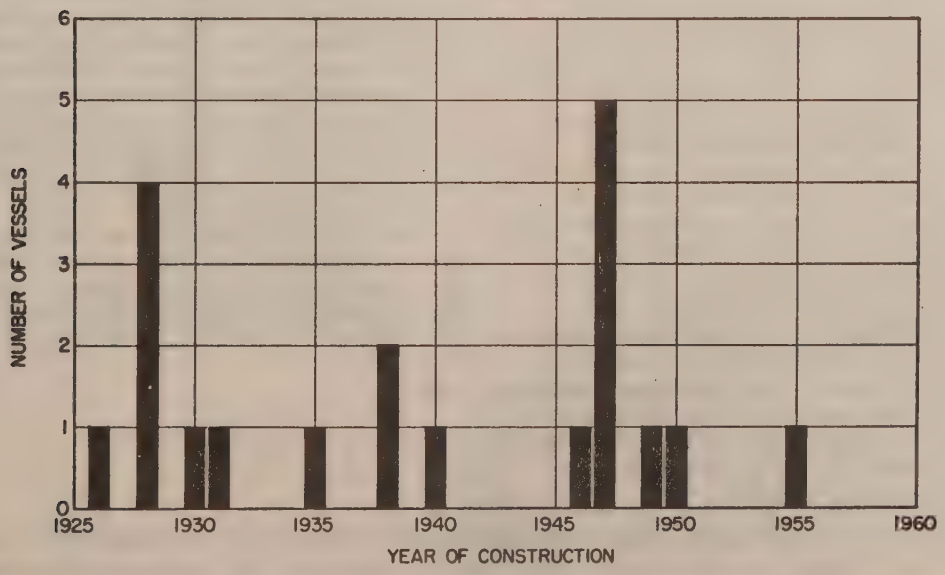


Fig. 2 Year of construction for skipjack boats active in 1961

# 1 INTRODUCTION

## 1.1 Present status of fishery[1/]

In today's economy of many vigorously growing industries the Hawaiian skipjack fishery gives many indications of slowly deteriorating. From a modest start in the early 1900's this fishery has increased in importance and magnitude and in recent years the skipjack landings have represented from 50 to 70 percent of the total fish landings in the State of Hawaii (Yamashita, 1958). Since 1948 the annual skipjack landings have varied between 2,750 to 6,350 metric tons (Fig. 1). Total landings however, do not show the serious condition facing the fishery; instead, a survey of the size and age of the fishing fleet more accurately depicts the existing situation. The history of the fishery in the post-World War II period shows an initial flurry of activity, born of optimism, which included the construction of nine new vessels between 1946 and 1950 (Fig. 2). This was followed by a stable period in the early 1950's when only one new vessel was added to the fleet. In recent years, with the withdrawal of a number of the older boats from the active fleet and the absence of new construction, the size of the fleet has been reduced from a total of 32 boats in 1948 (June 1951) to the present total of 20 boats. Even with the withdrawal of some of the older boats the present fleet may still be considered old; of the 20 boats fishing today, 7 were built between 1926 and 1931.

While the factors responsible for this state of decay in the fishery are complex, they are basically related to the wide fluctuations in the catch from year to year and to a method of fishing, with pole-and-line and live bait, which has remained virtually unchanged since the beginning of the fishery. This unchanging level of fishing efficiency, in combination with today's constantly rising operational costs, has had serious effects throughout the fishing industry, particularly during poor seasons. A similar situation which confronted the west coast tuna industry a few years back was resolved by increasing the fishing efficiency of the purse seiners by using nets of synthetic fiber and powerblocks to haul the nets (McNeely, 1961). Today the west coast fishery has regained its former stature of a thriving industry.

With regard to the efficiency of the pole-and-line fishery, there are several points on which this method can be considered inefficient. Studies by the U. S. Bureau of Commercial Fisheries Biological Laboratory in Honolulu show that approximately 50 percent of the fish schools actively pursued and chummed do not respond to the chum (Royce and Otsu, 1955; Yuen, 1959). Observations made on commercial boats also show that the catch per school is very small, suggesting that only a small fraction of each school is being landed. Yuen (1959) counted the catch from 73 schools successfully fished by commercial fishermen. The catch from 20 of the 73 schools (27 percent) was less than 25 fish per school and 53 (73 percent) of the schools gave catches numbering less than 125 fish per school (Fig. 3a). An additional factor contributing to the low catches is the relatively short time each school is fished. Of a total of 72 schools examined 60 (83 percent) were fished for a period of less than 25 minutes (Fig. 3b).

In essence, the solution to restoring the Hawaiian skipjack fishery into the family of growing industries is to increase the level of fishing efficiency, either by (1) improving the existing pole-and-line method or (2) introducing an entirely different mode of fishing. The present study is primarily concerned with the latter approach.

# 2 BACKGROUND MATERIAL

## 2.1 Plans

Prior to the field trials carried out from a chartered skipjack boat, a program was outlined which included: (1) an evaluation of the operational aspects of fishing monofilament gill nets, to be carried out on the Bureau's research vessel Charles H. Gilbert; and (2) a listing of possible methods of fishing the gear. The methods either fell into an active fishing category, in which a skipjack school is pursued and the net set in the midst of the school, or into a passive fishing category, where the net is set at a predetermined location and allowed to drift over a period of time, usually during the hours of darkness.

1/ This study is being jointly financed by the State of Hawaii and the Bureau of Commercial Fisheries. Funds from the latter were made available by the Saltonstall-Kennedy Act.

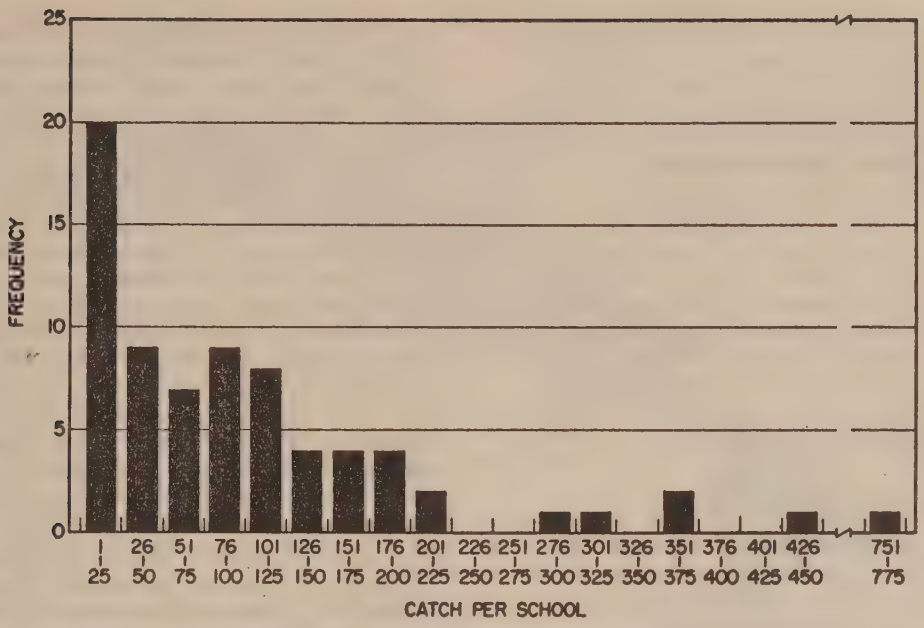


Fig. 3a Frequency distribution of skipjack catch per school (data from Yuen, 1959)

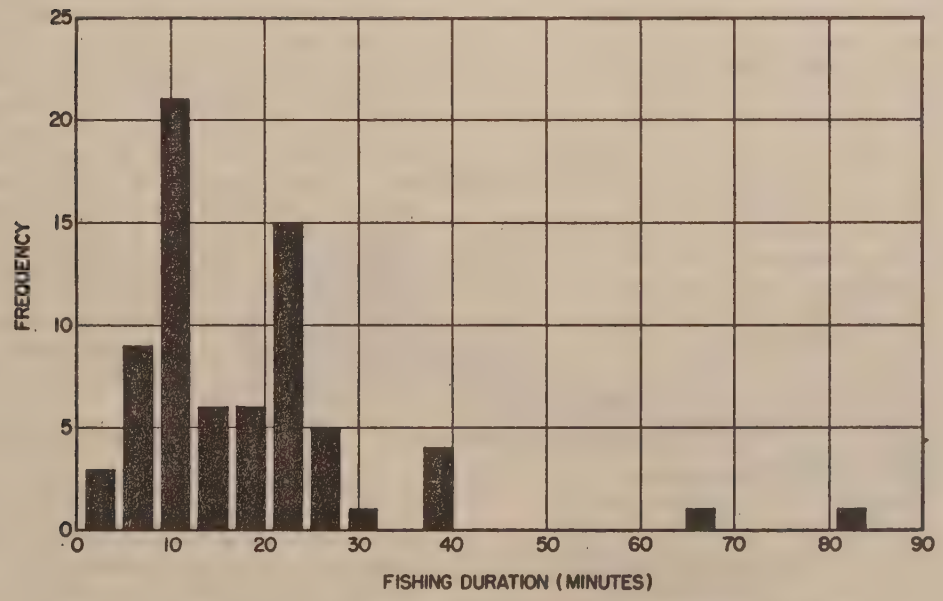


Fig. 3b Frequency distribution of fishing duration (data from Yuen, 1959)

Because of circumstances, including the availability of funds in late June and the receipt of gear in early July, the field program did not get underway until July 23, 1961. This late start was detrimental to the field program, since the skipjack fishery is seasonal with the peak catches made from June through August. In 1961 the effect of the delay was aggravated by the start of the fishing season a month earlier than usual. For these reasons, when field work was suspended on September 29, 1961, we were still in the early stages of evaluating modifications of the gear, and we were unable to do any work on the passive fishing phase of the program.

### 2.2 Monofilament nets

Before detailing the types and specifications of the monofilament gill nets purchased and used in the experiments, some information on the nature of monofilament is necessary to point out its advantages over other netting materials.

In recent years the use of monofilament fiber for gill nets has increased considerably throughout the world. Monofilament is one of several synthetic fibers commonly known under the general term "nylon." These fibers belong to the polyamide group, which along with other synthetic fibers have revolutionized the textile and fishing industries. Among the advantages nylon possesses over natural fibers are: (1) it is virtually unaffected by age, (2) it loses strength only on prolonged exposure to sunlight, (3) it is resistant to many chemicals, and (4) it is immune to bacteria, which permits leaving the gear in water for prolonged periods of time. The important attribute of monofilament nylon fiber is its very high transparency in water, which gives it a higher fishing efficiency than natural or other synthetic fibers. Molin (1959) discussed the results of comparative fishing tests using gill nets made of cotton, multifilament nylon, and monofilament nylon fibers. He reported that monofilament gill nets caught more than 7 times as many fish as cotton nets and approximately 4 times as many fish as multifilament nylon nets. The fishing efficiency of monofilament is so high that the states of Washington, Oregon and Alaska have banned these nets for salmon fishing.

The monofilament gill nets used in the field trials in Hawaiian waters were of clear fiber of two mesh sizes. Based on simple tests consisting of passing skipjack of various sizes through mesh of different sizes, 5-1/2 in. (13.97 cm.) mesh (stretched measure) was selected for skipjack ranging from about 2 to 5 kilograms. The fiber for the 5-1/2 in. mesh net was 22 MF (approximately 22-pound test line). Since the bulk of the season's catch is usually made up of fish ranging in size from 8 to 10 kilograms, monofilament nets made up of 7-3/4 in. (19.68 cm.) mesh (stretched measure) were chosen for catching these fish. The fiber for the 7-3/4 in. mesh net was 35 MF (approximately 35-pound test line). Each unit of gear, called a shackle, measured 100 fathoms (hung measure) along the corkline and 102 fathoms (hung measure) along the leadline. The webbing was hung-in 50 percent along the corkline, i.e. 200 fathoms of webbing was hung on 100 fathoms of corkline. The 5-1/2 in. and the 7-3/4 in. nets both measured 10 fathoms in depth.

### 2.3 Vessel

Since the results of field trials must be applicable to the existing skipjack fleet, it was desirable to carry out the field work from a commercial skipjack boat. In this way the efficiency of the gear, the operational costs, and the earnings from the catch would be directly comparable with those of the commercial boats. For these reasons a commercial boat, M/V Broadbill was chartered. The Broadbill is typical of the sampan-type boats used exclusively in the Hawaiian skipjack fishery. She is 20.4 meters in length, has a sharp and high bow, and the pilot house is located just forward of midship (Fig. 5). The entire after section is open and low to allow for efficient pole fishing from the stern.

### 2.4 Results of preliminary trial

In May 1961, preliminary tests were carried out on the Charles H. Gilbert. Operational aspects of fishing the gear were examined and a simple comparative fishing test using only a single shackle of monofilament gill net was tried. The net was 100 fathoms long, 4 fathoms deep, and the mesh was 5-1/2 in. (stretched measure). For comparison a 50-fathom length of multifilament nylon, dyed green was attached to each end of the monofilament shackle. The

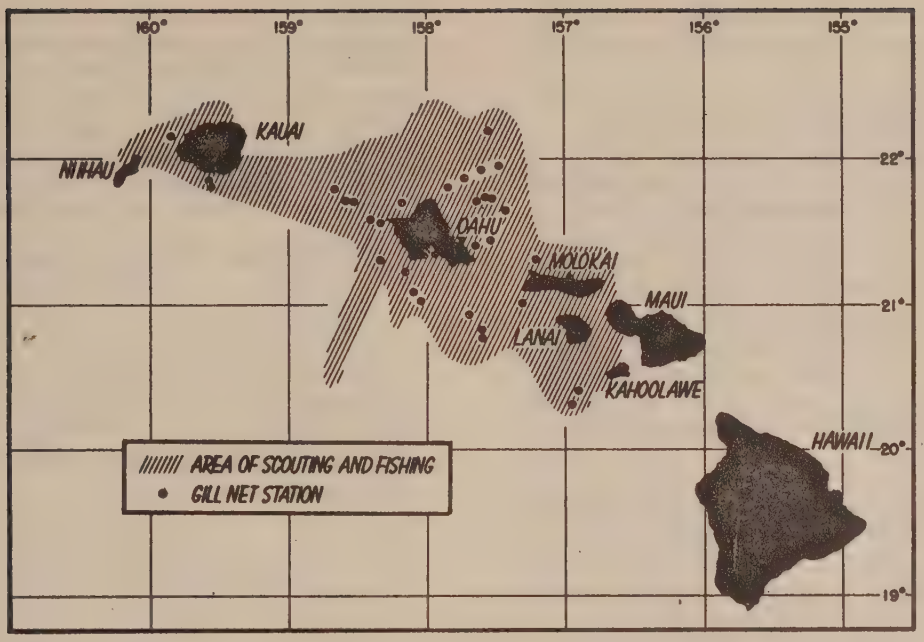


**Fig. 4 Area of scouting and fishing, M/V Broadbill; July 23, 1961 - September 29, 1961**

**Fig. 5 Schematic diagram of M/V Broadbill**

mesh size of the multifilament net was also 5-1/2 in. (stretched measure).

The method of fishing developed in the preliminary trial, which appeared to be applicable on a skipjack boat, was to (1) locate a skipjack school by the usual method of looking for a "working" bird flock, (2) pursue and chum the school to the stern of the boat with live bait, and (3) pay-out the gill net from a wooden bin situated at the stern of the boat. During the setting operations chumming was continued, and upon completion of the set the vessel was maneuvered into a position with the bow at the net and chumming was then continued from the bow.

The results from three sets showed that skipjack can be taken by this method of active gill net fishing. The distribution of the catches also revealed the superiority of the monofilament netting over the multifilament nylon netting. Catches for the three sets were 34, 63, and 225 skipjack and only 5 of these were taken on the two multifilament nylon sections.

Direct observations of the net and the reaction of the skipjack to it were made through the underwater chambers of the Gilbert. The "hang" of the monofilament section in the water appeared ideal, with the meshes open and the leadline straight. The multifilament section, on the other hand, tended to bunch in, causing the meshes to close. In terms of visibility the difference between the two types of nets was striking, the monofilament net being far more transparent and difficult to see than the multifilament nylon. Observations on the reaction of the skipjack to the net were somewhat puzzling. At the multifilament sections the skipjack were apparently able to see the net at a considerable distance and avoided coming close to it. At the monofilament section the skipjack seemed to show a similar avoidance reaction at times. This, however, was not always the case as attested by the catch and also by some direct observations of fish being gilled. On a number of occasions skipjack were seen hitting the net at a relatively slow speed (unlike a feeding dash), suggesting that they did not see the webbing.

In order to evaluate the ability of skipjack to see monofilament line, five skipjack were caught by the pole-and-line method and transported alive to the ponds at Kewalo. These ponds were specifically constructed for tuna behavior studies (Nakamura, 1960). Although the test was limited in scope, it did show that skipjack are capable of seeing monofilament lines (22-pound test line was used) and avoiding them.

## 3 RESULTS OF 1961 FIELD TRIALS

### 3.1 General

Field work on board the M/V Broadbill commenced on July 23, 1961. Until operations were suspended on September 29, 1961, 45-1/2 days were spent in baiting, scouting, and fishing (Table I).

Table I

Distribution of effort:
July 23 to September 29, 1961

| | |
|---|---|
| Days spent baiting | 18 |
| Days spent scouting and fishing | 27-1/2 |
| Days running without bait | 1-1/2 |
| Days spent repairing vessel and gear | 10 |
| Days of rest | 12 |
| TOTAL DAYS | 69 |

The time schedule and the sequence of operations followed during the 2 months of field work were similar to those of the commercial skipjack boats. These involved locating and catching a supply of bait fish, taking on ice and other supplies, and then scouting and fishing the general areas where good commercial catches were being made. Fig. 4 shows the general area of scouting and fishing, while Table II lists the stations and type of activity undertaken.

### 3.2 Operational data

One of the major factors often overlooked when considering fishing in Hawaiian waters is the generally prevailing sea state and the closely related wind force. The Hawaiian Islands chain is located in the trade wind zone, and sea conditions usually range from "choppy" to "rough." Murphy and Niska (1953), in describing purse seining operations, considered the wind and sea conditions as principal factors limiting the use of this method of fishing in Hawaiian waters. Table III, taken

Table II

STATION LIST, M/V BROADBILL, JULY 23, 1961 TO SEPTEMBER 29, 1961

| Station | Date | Position 1/ Latitude | Longitude | Type of Activity |
|---|---|---|---|---|
| 1 | 7/23/61 | Pearl Harbor | | baiting - nehu 2/ |
| 2 | 7/24/61 | 21° 18.1' N. | 158° 13.7' W. | chummed - abandoned - small skipjack |
| 3 | 7/24/61 | 21° 15.2' | 158° 10.2' | chummed - abandoned - no response - med. skipjack |
| 4 | 7/24/61 | 21° 36.9' | 158° 19.6' | chummed - abandoned - no response - sml. skipjack |
| 5 | 7/25/61 | *21° 34' | 158° 19' | chummed - set 5-1/2" net |
| 5A | 7/25/61 | 21° 34' | 158° 19' | chummed - abandoned - small yellowfin |
| 6 | 7/25/61 | 21° 33.1' | 158° 16.5' | abandoned - porpoise |
| 7 | 7/25/61 | 21° 22.4' | 158° 20.5' | chummed - abandoned - small skipjack |
| 8 | 7/25/61 | 21° 09.4' | 158° 01.5' | chummed - abandoned - small skipjack |
| 9 | 7/26/61 | Pearl Harbor | | baiting - nehu |
| 10 | 7/27/61 | *21° 00' | 157° 30' | chummed - abandoned - mahimahi 2/ |
| 11 | 7/27/61 | *20° 45' | 157° 05' | trolled around log |
| 11A | 7/27/61 | 3/4 mile south of Cape Kaea, Lanai | | blind chumming - abandoned - no response |
| 12 | 7/29/61 | Kuliouou Stream | | baiting - mosquito fish |
| 13 | 7/31/61 | Pearl Harbor | | baiting - nehu |
| 14 | 7/31/61 | 21° 13.5' | 158° 02.3' | chummed - abandoned - no response |
| 15 | 7/31/61 | *21° 10' | 158° 08' | chummed - abandoned - no response - med. skipjack |
| 16 | 7/31/61 | *21° 10' | 158° 08' | chummed - abandoned - small skipjack |
| 17 | 7/31/61 | 21° 05.7' | 158° 11.1' | chummed - abandoned - small skipjack |
| 18 | 7/31/61 | 21° 04.5' | 158° 11.2' | chummed - set 7-3/4" net |
| 19 | 7/31/61 | 21° 01.7' | 158° 10.1' | chummed - set 5-1/2" net |
| 20 | 8/1/61 | 20° 47.5' | 158° 43.6' | chummed - abandoned - no response |
| 21 | 8/1/61 | 21° 13.5' | 158° 25.4' | chummed - abandoned - small skipjack |
| 22 | 8/1/61 | *21° 20' | 158° 20' | chummed - set 5-1/2" net |
| 23 | 8/2/61 | *21° 23' | 158° 12' | blind chumming - abandoned - no response |
| 24 | 8/2/61 | Off Barber's Point, Oahu | | chummed - abandoned - no response |
| 24A | 8/2/61 | Off Ewa Beach | | blind chumming - abandoned - no response |
| 25 | 8/3/61 | Pearl Harbor | | baiting - nehu |
| 26 | 8/4/61 | 21° 02.0' | 157° 20.2' | chummed - set 5-1/2" net |
| 27 | 8/4/61 | 5-10 miles southwest of Lanai | | trolled around log |
| 27A | 8/4/61 | 5-10 miles south of Lanai | | chummed skipjack school - abandoned - no response |
| 28 | 8/5/61 | Kaiwi Channel | | chummed - abandoned - no response |
| 29 | 8/5/61 | 5-10 miles northeast Makapuu Pt., Oahu | | chummed - set 5-1/2" net |
| 30 | 8/9/61 | Pearl Harbor | | baiting - nehu |
| 31 | 8/10/61 | 5-10 miles southeast Barber's Pt., Oahu | | chummed - abandoned - no response |
| 32 | 8/10/61 | 21° 05.9' | 158° 25.1' | chummed - abandoned - yellowfin |
| 33 | 8/10/61 | 21° 41.2' | 158° 09.0' | chummed - set 5-1/2" net |
| 34 | 8/11/61 | 5-10 miles north of Kahuku Pt., Oahu | | chummed - abandoned - small skipjack |
| 35 | 8/11/61 | 5-10 miles west of Kahuku Pt., Oahu | | abandoned - school sounded |
| 36 | 8/11/61 | 21° 35.9' | 158° 21.2' | chummed - abandoned - small unidentified fish |
| 37 | 8/11/61 | 21° 31.3' | 158° 15.9' | chummed - set 7-3/4" net |
| 38 | 8/11/61 | 21° 09.6' | 158° 13.0' | chummed - abandoned - little tunny |
| 39 | 8/11/61 | 21° 13.9' | 158° 10.4' | chummed - set 5-1/2" net |
| 40 | 8/13/61 | Pearl Harbor | | baiting - nehu |
| 41 | 8/14/61 | 21° 38.4' | 157° 29.1' | chummed - set 7-3/4" net |
| 42 | 8/14/61 | 21° 44.5' | 157° 30.9' | chummed - set 7-3/4" net |
| 43 | 8/14/61 | 21° 33.6' | 157° 23.8' | chummed - set 7-3/4" net |
| 44 | 8/14/61 | 21° 33.2' | 157° 28.8' | chummed - abandoned - skipjack school sounded |
| 45 | 8/14/61 | ca. 5 miles north of Makapuu Pt., Oahu | | chummed - set 5-1/2" net |
| 46 | 8/15/61 | Pearl Harbor | | baiting - nehu |
| 47 | 8/16/61 | Keehi Lagoon | | baiting - iao 2/ |
| 48 | 8/16/61 | Kaneohe Bay | | night baiting - iao |
| 49 | 8/17/61 | Kaneohe Bay | | baiting - iao |
| 50 | 8/17/61 | *21° 40' | 157° 35' | chummed - abandoned - no response |
| 51 | 8/17/61 | *21° 17' | 157° 12' | chummed - set 5-1/2" net |
| 52 | 8/18/61 | 21° 13.7' | 157° 24.0' | chummed - abandoned - small unidentified fish |
| 53 | 8/18/61 | 21° 12.1' | 157° 28.5' | chummed - abandoned - mahimahi |
| 54 | 8/18/61 | 20° 49.3' | 157° 37.0' | Porpoise |
| 55 | 8/18/61 | 20° 52.6' | 157° 39.0' | chummed - abandoned - small skipjack |
| 56 | 8/18/61 | 20° 50.4' | 157° 43.1' | chummed - abandoned - small skipjack |
| 57 | 8/18/61 | 20° 55.8' | 157° 46.7' | chummed - abandoned - small skipjack |
| 58 | 8/29/61 | Pearl Harbor | | baiting - nehu |
| 59 | 8/30/61 | 21° 32.3' | 158° 21.1' | chummed - abandoned - small skipjack |
| 60 | 8/30/61 | 21° 38.2' | 158° 26.9' | chummed - abandoned - small skipjack sounded |
| 61 | 8/30/61 | *21° 40' | 158° 28' | chummed - set 5-1/2" net |
| 62 | 8/30/61 | 21° 43.5' | 158° 31.9' | chummed - set 5-1/2" net |
| 63 | 8/30/61 | *21° 40' | 158° 30' | chummed - set 5-1/2" net |
| 64 | 8/30/61 | 21° 38.0' | 158° 30.0' | chummed - abandoned - mahimahi |
| 65 | 8/30/61 | *21° 30' | 158° 25' | chummed - abandoned - small unidentified fish |
| 66 | 8/31/61 | *21° 34' | 158° 21' | chummed - set 5-1/2" net |
| 67 | 8/31/61 | 21° 15.0' | 158° 26.8' | chummed - abandoned - no response |
| 68 | 9/1/61 | Pearl Harbor | | baiting - nehu |
| 69 | 9/2/61 | *21° 39' | 158° 11' | abandoned - school sounded |

1/ Positions preceded by * are based on dead reckoning.
2/ Nehu - Stolephorus purpureus; mahimahi - Coryphaena hippurus; iao - Pranesus insularum.

Table II

STATION LIST, M/V BROADBILL, JULY 23, 1961 TO SEPTEMBER 29, 1961 (con.)

| Station | Date | Position 1/ Latitude | Longitude | Type of Activity |
|---|---|---|---|---|
| 70 | 9/2/61 | 22° 02.7' | 157° 53.6' | chummed - abandoned - no response |
| 71 | 9/2/61 | *22° 56' | 157° 48' | chummed - abandoned - no response |
| 72 | 9/2/61 | *21° 49' | 157° 42' | chummed - abandoned - school sounded (skipjack) |
| 73 | 9/2/61 | 21° 44.0' | 157° 30.5' | chummed - set 7-3/4" net |
| 74 | 9/2/61 | 21° 43.9' | 157° 46.1' | chummed - set 5-1/2" net |
| 75 | 9/3/61 | 21° 40.0' | 157° 34.2' | chummed - abandoned - no response (large skipjack) |
| 76 | 9/3/61 | *21° 40' | 157° 30' | chummed - set 7-3/4" net |
| 77 | 9/3/61 | *21° 38' | 157° 31' | chummed - abandoned - no response (large skipjack) |
| 78 | 9/3/61 | *21° 30' | 157° 31' | chummed - abandoned - no response (large skipjack) |
| 79 | 9/3/61 | 21° 39.1' | 157° 32.1' | chummed - set 7-3/4" net |
| 80 | 9/5/61 | Pearl Harbor | | baiting operation - nehu |
| 81 | 9/6/61 | 21° 37.0' | 157° 30.9' | chummed - abandoned - no response |
| 82 | 9/6/61 | 21° 44.2' | 157° 34.4' | chummed - abandoned - mahimahi |
| 83 | 9/6/61 | 21° 44.2' | 157° 34.4' | chummed- abandoned - no response |
| 84 | 9/6/61 | 21° 46.0' | 157° 34.5' | chummed - abandoned - mahimahi |
| 85 | 9/6/61 | 21° 51.1' | 157° 31.6' | chummed - abandoned - no response |
| 86 | 9/7/61 | 20° 53.5' | 157° 04.9' | blind chumming - abandoned - no response |
| 87 | 9/7/61 | *20° 48' | 157° 02' | chummed - abandoned - small skipjack |
| 87A | 9/7/61 | *20° 48' | 157° 02' | chummed - abandoned - no response (mixed small & med. |
| 88 | 9/7/61 | 20° 27.4' | 156° 59.2' | chummed - set 5-1/2" net size skipjack) |
| 89 | 9/7/61 | 20° 24.2' | 157° 0?.2' | chummed - set 5-1/2" net |
| 89A | 9/8/61 | 21° 06.6' | 157° 40.9' | chummed - abandoned - no response |
| 90 | 9/8/61 | 21° 01.7' | 157° 51.1' | chummed - abandoned - mahimahi |
| 91 | 9/8/61 | 20° 50.1' | 157° 59.4' | chummed - abandoned - mahimahi |
| 92 | 9/8/61 | 21° 11.1' | 158° 07.9' | chummed - soandoned - mahimahi |
| 93 | 9/8/61 | Off Ewa Beach | | blind chumming - abandoned - no response |
| 94 | 9/8/61 | Off Ewa Beach | | chummed - abandoned - small skipjack |
| 95 | 9/10/61 | Pearl Harbor | | baiting operation - nehu |
| 96 | 9/11/61 | 21° 45.5' | 157° 23.0' | chummed - set 7-3/4" net |
| 97 | 9/11/61 | 21° 51.0' | 157° 24.0' | chummed - abandoned - no response |
| 98 | 9/11/61 | 21° 56.5' | 157° 23.2' | chummed - set 7-3/4" net |
| 99 | 9/11/61 | 21° 59.0' | 157° 21.8' | chummed - abandoned - no response |
| 100 | 9/11/61 | 22° 00.6' | 157° 22.0' | chummed - abandoned - small skipjack |
| 101 | 9/11/61 | 21° 59.1' | 157° 22.9' | chummed - abandoned - small skipjack |
| 102 | 9/12/61 | Pearl Harbor | | baiting operation - nehu |
| 103 | 9/13/61 | 21° 36.5' | 157° 28.1' | chummed - abandoned - no response |
| 104 | 9/13/61 | 21° 28.9' | 157° 25.8' | chummed - abandoned - no response |
| 105 | 9/13/61 | 21° 53.6' | 157° 42.2' | chummed - abandoned - small skipjack |
| 106 | 9/13/61 | 21° 53.0' | 157° 28.5' | abandoned - small skipjack |
| 107 | 9/13/61 | 21° 54.0' | 157° 27.0' | chummed - pole-and-line only - small skipjack |
| 108 | 9/13/61 | 21° 46.3' | 157° 30.8' | chummed - abandoned - no response |
| 109 | 9/13/61 | 21° 48.5' | 157° 29.5' | chummed - abandoned - no response |
| 110 | 9/13/61 | *21° 48' | 157° 29' | chummed - abandoned - small skipjack |
| 111 | 9/13/61 | Off Mokumanu, Oahu | | chummed - abandoned - no response |
| 112 | 9/16/61 | Pearl Harbor | | baiting operation |
| 112A | 9/17/61 | *21° 50' | 159° 35' | chummed - skipjack school sounded |
| 113 | 9/17/61 | *21° 50' | 159° 35' | chummed - set 5-1/2" net |
| 114 | 9/17/61 | *21° 50' | 159° 35' | chummed - set 5-1/2" net |
| 115 | 9/18/61 | Port Allan, Kauai | | baiting operation - nehu |
| 116 | 9/18/61 | *22° 06' | 159° 49' | chummed - set 5-1/2" net |
| 117 | 9/18/61 | Hanalei Bay, Kauai | | baiting operation - nehu |
| 118 | 9/19/61 | *22° 07' | 160° 07' | chummed - abandoned - no response |
| 119 | 9/19/61 | *22° 01' | 160° 01' | chummed - abandoned - school sounded |
| 120 | 9/19/61 | *21° 54' | 159° 42' | chummed - abandoned - small unidentified fish |
| 121 | 9/20/61 | Kauai Channel | | no attempt - lack of bait |
| 122 | 9/21/61 | Pearl Harbor | | baiting operation - nehu |
| 123 | 9/22/61 | Pearl Harbor | | baiting operation - nehu |
| 124 | 9/23/61 | 20° 56.5' | 157° 46.5' | chummed - abandoned - no response |
| 125 | 9/23/61 | 20° 56.5' | 157° 46.5' | chummed - set 5-1/2" net |
| 126 | 9/23/61 | 20° 52.3' | 157° 45.4' | chummed - set 5-1/2" net |
| 127 | 9/23/61 | 20° 53.2' | 157° 45.3' | chummed - set 5-1/2" net, 7-3/4" net |
| 128 | 9/26/61 | Keehi Lagoon | | baiting operation - nehu |
| 129 | 9/27/61 | 21° 23.8' | 158° 27.7' | chummed - abandoned - no response |
| 130 | 9/27/61 | *21° 31' | 158° 17.5' | chummed - abandoned - small unidentified fish |
| 131 | 9/28/61 | 21° 15.5' | 157° 29.5' | abandoned - porpoise |
| 132 | 9/28/61 | 20° 58' | 157° 27' | chummed - abandoned - no response |
| 133 | 9/28/61 | 20° 58' | 157° 27' | chummed - abandoned - no response |
| 134 | 9/28/61 | 20° 58.4' | 157° 27.1' | chummed - abandoned - school sounded |
| 135 | 9/28/61 | 20° 58' | 157° 27' | chummed - abandoned - small skipjack |

from the above paper, shows the average monthly wind force for several areas in the Pacific for 1951. The Hawaiian area shows a considerably higher proportion of force 4 (11 to 16 knots) or stronger winds than the other areas listed. The significance of these conditions is emphasized by the fact that the period of greatest trade wind predominance occurs during the summer, which is also the peak of the skipjack season.

Based on our limited experience, the gill net can easily and safely be fished in sea states up to wave heights of 2 to 3 meters and under wind forces estimated between 18 and 20 knots (Table IV). In rough seas the gill net acted as a sea anchor during hauling of the net.

The procedure of fishing the gill net from the Broadbill was the same as that developed in the preliminary trials on the Charles H. Gilbert. The nets were set from a 3 m. x 3.7 m. x 0.9 m. wooden bin attached to the stern of the Broadbill (Fig. 5).

The net was allowed to pay-out freely while the vessel moved ahead at chumming speed (1-1/2 to 2 knots). The time required to set a 100-fathom shackle was approximately 2 minutes.

At the start of the field trials, the powerblock for hauling the net was situated on an H-frame which was located about amidships (Fig. 5). The net along with the catch was pulled over the powerblock and onto the deck. After hauling had been completed, the fish were removed from the net and the net was re-stacked in the bin. Although the hauling operation went very well in slight seas and winds, it became very difficult under strong trade wind conditions. This difficulty was traced to our inability to manèuver the vessel in proper relation to the lay of the net. To increase maneuverability the powerblock was relocated to a davit on the port side just forward of the wheelhouse (Figs. 5 and 6). This modification improved the hauling operation considerably. The hauling time (Table V) ranged from 7 to 45 minutes and averaged 14 minutes for 21 sets in which times were recorded. The catches on these sets ranged from 0 to 103 skipjack.

The most difficult aspect of gill net operation is the removal of fish from the net and the re-stacking of the net. In our experience, the time taken for the picking and re-stacking phases was much too long for purposes of commercial application (Fig. 7). It will be necessary to reduce the time by 50 percent or more in order to make the gill net method of fishing commercially feasible.

Before the field work ended the hauling technique was slightly modified in an attempt to reduce the total time required for the hauling--re-stacking phase. We noted that a large part of the catch became badly entangled after passing over the powerblock, primarily because it was necessary to bunch the 10

Table III

Percentage of force 4 or higher winds; (Murphy and Niska, 1953) [1/]

| Month | Hawaiian Islands | Cape San Lucas, Baja California | Line Islands | Phoenix Islands |
|---|---|---|---|---|
| Jan. | 63 | - | 16 | 46 |
| Feb. | 36 | - | 91 | 41 |
| March | 67 | - | 25 | 4 |
| April | 29 | - | 22 | - |
| May | 49 | - | 11 | - |
| June | 82 | - | 41 | - |
| July | 91 | - | 32 | 15 |
| Aug. | 89 | - | - | 32 |
| Sept. | 84 | 4 | 94 | - |
| Oct. | 46 | 2 | 22 | 10 |
| Nov. | 44 | - | 11 | 55 |
| Dec. | 76 | - | 50 | 17 |

[1/] Data from U. S. Pilot Chart for 1951.

Fig. 6a Gill net powerblock secured to davit on port side of M/V Broadbill

Fig. 6b Hauling-in of skipjack catch

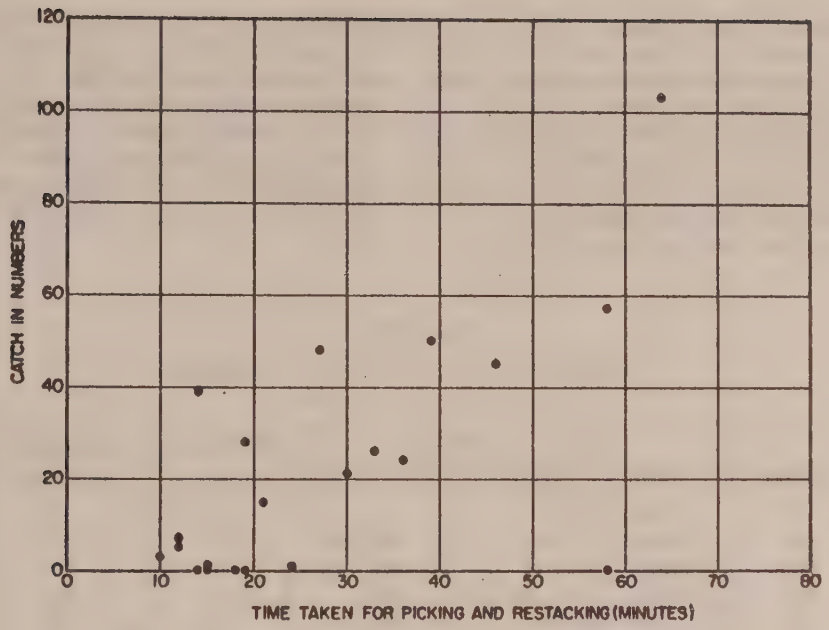


**Fig. 7 Relation of total catch with time taken for picking and re-stacking**

fathoms of webbing in the process. As a result of this bunching fish which were initially gilled in a single mesh inevitably became enmeshed in several others. The modification simply involved the removal of as many fish as possible before the net moved over the powerblock. Although an evaluation of this modification requires further trials, we feel that the increase in hauling time would be more than compensated for by the reduction in the time taken for picking and re-stacking. Moreover, the marketability of the fish should improve from the elimination of their contact with the powerblock. A further quality improvement should also result from the reduction in the time between capture and refrigeration of the fish.

Table IV

Summary of environmental conditions on gill net stations

| Station | Date | Wind | | State of sea | Secchi disc reading |
|---|---|---|---|---|---|
| | | Force | Direction | | |
| 5 | 7/25/61 | | | 1-3 | |
| 18 | 7/31/61 | 4-6 | NE (?) | < 1 | |
| 19 | 7/31/61 | 4-6 | NE (?) | < 1 | |
| 22 | 8/11/61 | 8-10 | NE | 1-3 | 35 |
| 26 | 8/4/61 | 10 | NE | 3-5 | 28 |
| 29 | 8/5/61 | 18-20 | NE | 5-8 | |
| 33 | 8/10/61 | 12-15 | NE | 3-5 | |
| 37 | 8/11/61 | 6-8 | W | < 1 | |
| 39 | 8/11/61 | 12-15 | ENE | 3-5 | |
| 41 | 8/14/61 | 6 | NE | 3-5 | 31 |
| 42 | 8/14/61 | 12-15 | NE | 5 | |
| 43 | 8/14/61 | 12 | NE | 5-8 | 32 |
| 45 | 8/14/61 | 10-12 | NE | 3-5 | |
| 51 | 8/17/61 | 22 | NE | 5-8 | |
| 61 | 8/30/61 | 10-12 | NE | 1-3 | |
| 62 | 8/30/61 | 8-10 | NE | 1-3 | |
| 63 | 8/30/61 | 10-12 | NE | 1-3 | |
| 66 | 8/31/61 | 4-6 | | < 1 | |
| 73 | 9/2/61 | 15 | NE | 3-5 | 32 |
| 74 | 9/2/61 | 13 | NE (?) | 3-5 | 33 |
| 76 | 9/3/61 | | | | |
| 79 | 9/3/61 | 11 | NE | 1-3 | 33 |
| 88 | 9/7/61 | 8 | NE | < 1 | 42 |
| 89 | 9/7/61 | 7 | NE | < 1 | 32 |
| 96 | 9/11/61 | 10 | NE | 3-5 | 33 |
| 98 | 9/11/61 | 7 | NE | 3-5 | 36 |
| 113 | 9/17/61 | 4-6 | SE | < 1 | |
| 114 | 9/17/61 | 3 | SE | < 1 | 36 |
| 116 | 9/18/61 | 8-10 | SE | | 34 |
| 125 | 9/23/61 | 8-10 | NE | 1-3 | |
| 126 | 9/23/61 | 10-12 | NE | 3-5 | |
| 127 | 9/23/61 | 14-16 | NE | 3-5 | |

Table V

Summary of hauling nets, picking fish and re-stacking

| Station | Mesh size of net | | Time taken for hauling (minutes) | Time taken for picking and re-stacking (minutes) |
|---|---|---|---|---|
| | 5-1/2 in. | 7-3/4 in. | | |
| 22 | x | | 11 | 14 |
| 26 | x | | 13 | 19 |
| 33 | x | | 45 | 30 |
| 37 | | x | 18 | 18 |
| 39 | x | | 13 | 46 |
| 41 | | x | 17 | 15 |
| 43 | | x | 9 | 15 |
| 45 | x | | 12 | 36 |
| 51 | x | | 11 | 58 |
| 62 | x | | 10 | 10 |
| 63 | x | | 11 | 27 |
| 66 | x | | 11 | 12 |
| 73 | | x | 9 | 24 |
| 79 | | x | 11 | 14 |
| 89 | x | | 15 | 64 |
| 98 | | x | 12 | 12 |
| 113 | x | | 7 | 19 |
| 114 | x | | 14 | 39 |
| 116 | x | | 11 | 33 |
| 125 | x | | 11 | 21 |
| 126 | x | | 13 | 50 |
| | Average time | | 13.5 | 27.8 |

### 3.3 Baiting

Although field tests not involving the use of live bait were part of the overall plans, the results from the preliminary trials indicated that the best approach initially was to incorporate the use of live bait.

Bait fishing was carried out according to the method developed by the commercial pole-and-line fishermen. This involves scouting for schools of bait fish, usually the nehu (Stolephorus purpureus), in the bay areas. After a school is located a small-mesh bait net is set around the school from a skiff powered with an outboard motor. The net usually measures 80 to 100 fathoms long and is about 4 fathoms deep. After the set has been made, the ends of the net are taken in until only a small "pocket" remains. If the skipjack boat is near, the bait is transported in the "pocket" to the boat where it is brailed into the bait holds. If the distance between the locality of capture and the boat is great, the bait is first brailed from the "pocket" into the holding well on the skiff, transported to the boat, and again brailed, this time into the bait holds. June (1951) gives a detailed description of the entire operation.

While the supply of bait was adequate, we were hindered by a high bait fish mortality rate. Although accurate measures of the mortality rate could not be made, because the bait supply was continually being diminished by fishing, we estimated that it ranged from a low of 30 percent to a high of 70 percent. It was not determined whether this high mortality was the result of poor aeration in the bait wells, conditions inherent in the bait fish themselves, or handling during capture.

3.4 Gill net fishing

In undertaking this experimental fishing we realized that the results could range from a complete failure of the monofilament gill net to capture skipjack to a complete success in which the netting method would supplant the pole-and-line method of fishing. Based on the magnitude of our initial catches it seemed unlikely that the netting method would result in an unqualified success; instead there were indications that the gill net could conceivably supplement the pole-and-line catch. After an initial period of trial and error we therefore used a combination of the two methods in order to maximize the skipjack catch. The procedure was to locate a skipjack school by means of a "working" bird flock and, following the standard pole-and-line method, chum the school to the stern of the boat. Upon determination of the size of the fish, either by estimating the size from surfacing skipjack or by the capture of a few fish by pole-and-line, the proper mesh-size net was set. Chumming was carried out at a heavy rate during the setting operation, then reduced to the level generally used during pole-and-line fishing. Immediately after the set the fishermen moved back to the stern and commenced pole-and-line fishing. The pole fishing was continued until the school either sounded or the biting rate slowed down. Subsequently the pole catch was iced and the hauling of the gill net started.

During the 27-1/2 days of scouting and fishing, 116 fish schools were sighted and investigated (Table VI). Although a few schools were located by sighting skipjack breaking the surface, the majority were located by means of "working" bird flocks. Of the total schools sighted, 66 (57 percent) were identified as skipjack, however, gill net sets were made on only 32 of these. The skipjack schools not fished were either made up of fish too small for the gill net (18 schools) or were schools which could not be stopped by chumming (16 schools). The remaining 50 schools were either unidentified, because they did not respond to the chum (35 schools), or were composed of species other than skipjack (15 schools).

In order to evaluate the effectiveness of the gill net it was found necessary to try modifications of the gear. In the early stages of the field program we used the gear as purchased from the manufacturer without any changes. The catches from eight gill net sets made with the unmodified nets are given in Table VII. The catches were discouraging, but several areas for improving the fishing efficiency of the gear were observed. During the setting operation it appeared that the gill net was not sinking fast enough. To test the possible influence of the sinking rate of the net on the catch, we cut a 100-fathoms 5-1/2 in net into two sections. We doubled the leadline on one section and left the other with a single leadline. The procedure was to set the two sections successively on the same school. To eliminate a possible bias in the catch the setting order of the two sections was alternated. The results of this experiment are given in Table VIII. Except for one set there does not appear to be a striking difference between the catches made by the two nets. The exception was station 88, where 122 skipjack were taken on the double-leadline net and only 5 on the single-leadline net. The explanation for this is that the double-leadline section was set first, and although the chumming rate was kept constant throughout the setting operation, the school sounded during the setting of the single-leadline section.

On the preliminary trials in May we were fairly successful in increasing the catch by positioning the boat with the bow at the net and continuing chumming from the bow. After the first month of field work we noticed that on many occasions the school sounded when the boat was stopped at the net. To make it possible to keep the boat in motion during the continued chumming we removed a 20-by 25-foot section from the middle of both a 5-1/2 in mesh net and a 7-3/4 in mesh net. The idea was to set the net, keep the school at the stern by chumming, and cross over the net at this "gate". At the point of crossing we would increase the chumming rate to get the skipjack in a feeding frenzy near the net and possibly increase the catch. The results of fishing with this modification are given in Table IX. While a direct evaluation of the fishing efficiency cannot be made, the catches do not appear to differ significantly from those made with the unmodified nets. In defense of the low catches it should be pointed out that the 7-3/4 in net was set on three schools which consisted of fish too large for the mesh size (stations 76, 79 and 96). Skipjack in these schools ranged from 22 to 37 pounds, whereas we believe that the 7-3/4 in mesh net is most effective for skipjack less than 22 pounds in weight. Direct evidence that the gate modification was not successful was the

Table VI

Summary of scouting and gill net fishing

| Date | Gill net set | | Schools not fished | | | | Total |
|---|---|---|---|---|---|---|---|
| | 5-1/2 in. | 7-3/4 in. | Skipjack No response | Small skipjack (< 3-4 lbs.) | Unidentified No response | Other species | |
| 7/24/61 | - | - | 2 | 1 | - | - | 3 |
| 25 | 1 | - | 1 | 1 | - | yellowfin, porpoise | 5 |
| 27 | - | - | - | - | - | mahimahi | 1 |
| 31 | 1 | 1 | 1 | 2 | 1 | - | 6 |
| 8/1/61 | 1 | - | - | 1 | 1 | - | 3 |
| 2 | - | - | 1 | - | 1 | - | 2 |
| 4 | 1 | - | 1 | - | - | mahimahi | 3 |
| 5 | 1 | - | - | - | 1 | - | 2 |
| 10 | 1 | - | - | - | 1 | yellowfin | 3 |
| 11 | 1 | 1 | - | 1 | 2 | little tunny | 6 |
| 14 | 1 | 3 | 1 | - | - | - | 5 |
| 17 | 1 | - | - | - | 1 | - | 2 |
| 18 | - | - | - | 3 | 1 | mahimahi, porpoise | 6 |
| 30 | 3 | - | 1 | 1 | 1 | mahimahi | 7 |
| 31 | 1 | - | - | - | 1 | - | 2 |
| 9/2/61 | 1 | 1 | 1 | - | 3 | - | 6 |
| 3 | - | 2 | 3 | - | - | - | 5 |
| 6 | - | - | - | - | 3 | 2 mahimahi | 5 |
| 7 | 2 | - | 2 | - | - | - | 4 |
| 8 | - | - | - | 1 | 2 | 3 mahimahi | 6 |
| 11 | - | 2 | - | 2 | 2 | - | 6 |
| 13 | - | - | - | 5 | 4 | - | 9 |
| 17 | 2 | - | 1 | - | - | - | 3 |
| 18 | 1 | - | - | - | - | - | 1 |
| 19 | - | - | - | - | 3 | - | 3 |
| 20 | - | - | - | - | 1 | - | 1 |
| 23 | 3 | - | - | - | 1 | - | 4 |
| 27 | - | - | - | - | 2 | - | 2 |
| 28 | - | - | 1 | - | 3 | porpoise | 5 |
| TOTAL | 22 | 10 | 16 | 18 | 35 | 15 | 116 |

Table VII

Results of fishing with the unmodified nets

| Station | Date | Gill net[1/] | Pole-and-line | Size range (pounds) | Comments |
|---|---|---|---|---|---|
| SKIPJACK CATCH | | | | | |
| 5-1/2 in Mesh Net | | | | | |
| 5 | 7/25/61 | 1 | 4 | 4-5 | Poor set--net payed-out in bunch. |
| 19 | 7/31/61 | 29 | 21 | 2-4 | |
| 22 | 8/1/61 | 39 (3) | 53 | 3-4 | |
| 26 | 8/4/61 | 28 | 39 | 2-4 | |
| 29 | 8/5/61 | 37 | 86 | 3-6 | Part of webbing (with undetermined number of gilled fish) cut off--net caught in propeller. |
| 33 | 8/10/61 | 21 (2) | 25 | 4-5 | School sounded shortly after setting completed. |
| 39 | 8/11/61 | 45 | 22 | 4-6 | |
| 45 | 8/14/61 | 24 (2) | 4 | 2-6 | |
| 7-3/4 in Mesh Net | | | | | |
| 18 | 7/31/61 | 1 | - | 3 | School sounded during setting operation. |
| 37 | 8/11/61 | - | 5 | 12-20 | School sounded at start of setting operation. |
| 41 | 8/14/61 | 1 | 5 | 26-37 | |
| 42 | 8/14/61 | - | 3 | 26-37 | |
| 43 | 8/14/61 | - | 5 | 29-36 | |

[1/] Numbers in ( ) represent fish lost at rail during hauling.

Table VIII

Relation between catching efficiency and sinking rate

| Station | Date | Double leadline | Single leadline | Pole-and-line | Size range (pounds) | Comments |
|---|---|---|---|---|---|---|
| SKIPJACK CATCH[1/] | | | | | | |
| 61 | 8/30/61 | - | Not set | 6 | 4 | School sounded after double leadline section set. |
| 62 | 8/30/61 | 3 | - | No pole fishing | 4 | |
| 63 | 8/30/61 | 31 | 17 (2) | 23 | 3-4 | |
| 66 | 8/31/61 | 1 | 6 | 7 | 3-6 | |
| 74 | 9/2/61 | 2 (1) | 12 (1) | 32 | 2-4 | |
| 88 | 9/7/61 | 117 (5) | 5 | 2 | 2-5 | School sounded during setting of the single leadline section. |
| 89 | 9/7/61 | 49 (2) | 54 (1) | 446 | 3-6 | |

[1/] Numbers in ( ) represent fish lost at rail during hauling.

Table IX

Results of fishing with a gate net

| Station | Date | Skipjack catch[1] Gill net | Skipjack catch[1] Pole-and-line | Size range of skipjack (lb.) | Passage through gate yes | Passage through gate no | Comments |
|---|---|---|---|---|---|---|---|
| **5-1/2 in. Mesh Net** | | | | | | | |
| 51 | 8/17/61 | -(1) | 13 | 3-8 | | x | Seas too rough for crossing over net. |
| 113 | 9/17/61 | - | 10 | - | | x | School sounded during setting operation. |
| 114 | 9/17/61 | 49 (2)[2] | 2 | 3-5 | | x | School sounded after setting operation. |
| 116 | 9/18/61 | 26 (1) | 76 | 3-5 | x | | |
| 125 | 9/23/61 | 15 | 7 | 3-6 | x | | |
| 126 | 9/23/61 | 55 (4)[3] | 138[4] | 4-6 | x | | |
| 127 | 9/23/61 | 27 | 59[5] | 5-7 | | x | School sounded after setting operation. |
| **7-3/4 in. Mesh Net** | | | | | | | |
| 73 | 9/2/61 | 1 | 4 | 14-16 | x | | |
| 76 | 9/3/61 | - | 1 | 28 | | x | Unable to stop school; net set in front of school. |
| 79 | 9/3/61 | - | 20 | 27-37 | x | | |
| 96 | 9/11/61 | 1 | 74 | 22-32 | | x | Gate section tangled. |
| 98 | 9/11/61 | 5 (2) | 21 | 9-16 | x | | Net set too soon--school not at stern. |

1/ Numbers in ( ) represent fish lost at rail during hauling.
2/ Additional catch: 1 mahimahi.
3/ Additional catch: 1 frigate mackerel; 1 small shark (species unknown).
4/ Additional catch: 1 frigate mackerel.
5/ Additional catch: 2 little tunny; 1 frigate mackerel.

reaction of three schools. On stations 116, 125 and 126 visual observations showed that the school was lost just as the boat passed through the gate. Prior to the time of crossing we were successfully fishing the school by pole-and-line, however, after we crossed the gate no skipjack were taken.

### 3.5 Cannery acceptability of gill net skipjack

In order to evaluate the acceptability of gill net-caught skipjack for canning three groups of fish were processed through the cannery. Each test included equal numbers of skipjack caught from the same school by the pole-and-line and gill net methods. Each fish was identified with a numbered metal tag and followed through the processing at the local cannery. The results of these three tests are given in Table X. In tests 1 and 3, definitely more blood spots occurred in the skipjack taken by the gill net method than those taken by the pole-and-line method. The results of test number 2, however, did not show such a differen

The conflicting results obtained from the three tests point out the desirability of additional acceptability experiments. At this point it seem unlikely, based on the results of the second test, that the method of capture is solely responsible for the amount of blood spotting. In a number of the gill net-caught fish bruises were noted in the cooked flesh, possibly resulting from injurie sustained while going over the powerblock. A solution to this problem, discussed earlier, is to develop a means of extracting the fish before the net passes over the powerblock.

Table X

Cannery acceptability tests of gill net-caught skipjack

| Degree of blood spots | Test No. 1 | | Test No. 2 | | Test No. 3 | |
|---|---|---|---|---|---|---|
| | Pole-and-line | Gill net | Pole-and-line | Gill net | Pole-and-line | Gill net |
| None | 1 | - | 1 | 1 | 3 | 1 |
| Slight | 24 | 16 | 20 | 18 | 4 | 3 |
| More than usual (compared to commercial pole-and-line catch) | - | 9 | 12 | 13 | 1 | 3 |
| Rejected | - | - | - | - | 2 | 3 |
| TOTAL | 25 | 25 | 33 | 32 | 10 | 10 |

## 4 DISCUSSION

From the results of the 2 months of field trials we have established that it is possible to capture skipjack with monofilament gill nets. We are, however, unable to judge the commercial applicability of this gear after such a short trial. In the 2 months we were only able to resolve some of the shortcomings in our methods of handling the gear, and we were still in the early stages of testing modifications of the gear.

Unless a modification of the gill net can be found which will increase the catching efficiency considerably above that so far experienced, the monofilament gill net will not supplant the pole-and-line method for catching commercial quantities of skipjack. There are indications, however, that the gear can be used effectively to supplement the catch made by the pole-and-line method. In the evaluation of the fishing efficiency of the pole fishery, evidence was presented that only a very small fraction of each skipjack school successfully fished was being landed. Since the number of schools successfully fished is also a low proportion of those fished (50 percent), any means of increasing the catch per school should be investigated. By incorporating a number of modifications in the gear and the operational method (see under Recommendations), we feel that the monofilament gill net can be used effectively to supplement the pole-and-line catch. We hope to test these modifications during the 1962 skipjack season.

## 5 RECOMMENDATIONS

The following are recommendations to be considered in the event this program is continued in 1962:

### 5.1 Bait fish

Use another kind of live bait, such as tilapia. Although the local anchovy (nehu) is a proven bait fish, the time taken to catch a load of bait fish and the high mortality rate of this species outweigh its proven quality of "raising" a school of skipjack to the stern of the boat.

### 5.2 Gill nets

Reduce the length of a shackle to 50 fathoms and the depth to 5 or 6 fathoms. The 100-fathom shackle is difficult to handle during the picking and re-stacking phase. Reducing the depth of the net will undoubtedly reduce the catch to some extent, but this would be compensated for by an appreciable reduction in the time taken for hauling, picking, and re-stacking. Under the present system too much time is spent in picking fish from the mass of webbing.

### 5.3 Setting modification

With a reduction in the size of the net the setting arrangement can be modified to increase fishing efficiency. Rather than set the nets from a large bin, which takes up the entire stern section, the setting can be done with the

nets stacked in troughs placed on either side of the vessel. Each 50-fathom net would occupy a single trough with the corkline forward and the leadline at the stern. A simple double deck arrangement would make it possible to carry four nets. This arrangement would then leave the entire stern section free for pole-and-line fishing during and after the setting operation. Under optimum conditions, with a large school at the stern of the vessel, two nets could be set simultaneously.

5.4 Hauling modification

Place the powerblock in the bow section close to the midline of the vessel. Moving the powerblock inboard will permit picking the catch from the net before it moves over the block. This should reduce the total time taken for hauling, picking, and re-stacking, since the catch can be removed from the net most easily at this point. In addition, the hauling modification will mean fewer fish being lost at the rail and better quality fish.

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Experience Paper No. 24

# GROWTH AND SEXUAL DIMORPHISM IN GROWTH OF BIGEYE TUNA (Thunnus obesus) A PRELIMINARY REPORT

By
RICHARD S. SHOMURA and BETTY ANN KEALA
U.S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

## Abstract

This report covers the results of a preliminary study on growth and sexual dimorphism in the growth of bigeye tuna. The analysis was limited to data collected from the Hawaiian longline fishery from April 1960 through March 1961. From 4 to 7 normal curves were fitted to each monthly weight distribution by the probability paper method. By making several assumptions a composite figure was constructed showing the estimated growth for male and female bigeye over a five-year period. The modal weights of male and female bigeye were used to fit the von Bertalanffy growth equation. The equation describes the growth of bigeye adequately and showed that males grew faster than females after age 3 (approximately 100 lbs). For males $W_\infty = 518$, $K = 0.114$, $t_o = 1.07$, and for females $W_\infty = 364$, $K = 0.167$, $t_o = 1.06$.

# THON OBESE (Thunnus obesus): CROISSANCE ET DIFFERENCES DU TAUX DE CROISSANCE SELON LE SEXE - RAPPORT PROVISOIRE

## Résumé

Le présent rapport fournit les résultats d'une étude préliminaire sur la croissance et les différences du taux de croissance selon le sexe chez le thon obèse. L'étude n'a porté que sur des données fournies d'avril 1960 à mars 1961 par la pêche aux palangres dans les eaux hawaiiennes. Par la méthode du papier à échelle fonctionnelle, on a ajusté de 4 à 7 courbes normales à chacun des histogrammes donnant mensuellement la composition des prises par poids. Sur la base de plusieurs hypothèses a été établi un graphique complexe indiquant pour une période de cinq ans l'estimation de la croissance du thon obèse mâle et femelle. On a utilisé les poids modaux du thon obèse mâle et femelle dans l'équation de croissance établie par von Bertalanffy. Celle-ci fournit une description satisfaisante de la croissance du thon obèse et révèle que les mâles se développent plus vite que les femelles après l'âge de 3 ans (correspondant approximativement à un poids de 100 pounds). Pour les mâles, $W_\infty = 518$, $K = 0,114$, $t_o = 1,07$, et pour les femelles, $W_\infty = 364$, $K = 0,167$, $t_o = 1,06$.

# CRECIMIENTO Y DIMORFISMO SEXUAL EN EL CRECIMIENTO DEL ATUN PATUDO (Thunnus obesus) INFORME PRELIMINAR

Extracto

Este informe comprende los resultados de un estudio preliminar sobre crecimiento y dimorfismo sexual en el crecimiento del patudo. El análisis se limitó a los datos recogidos de la pesquería hawaiana con palangre desde abril de 1960 a final de marzo de 1961. Se ajustaron de 4 a 7 curvas normales a cada una de las distribuciones mensuales de peso por el método del papel de probabilidad. Partiendo de varios supuestos se construyó una gráfica compuesta que mostraba el crecimiento estimado de los ejemplares machos y hembras de patudo en un período de 5 años. Los pesos modales de los machos y las hembras se utilizaron para ajustar la ecuación de crecimiento de Von Bertalanffy. Esta ecuación describe adecuadamente el crecimiento del patudo y mostró que los machos crecen más rápidamente que las hembras después de la edad 3 (aproximadamente 100 libras). Para los machos $W_\infty = 518$, $K = 0,114$, $t_o = 1,07$, y para las hembras $W_\infty = 364$, $K = 0,167$, $t_o = 1,06$.

## 1 INTRODUCTION

A persistent feature in the size distribution of the bigeye and yellowfin (Thunnus albacares) tuna catches from the Pacific has been the predominance of males among the larger fish (Murphy and Otsu 1954, Iversen 1955, Murphy and Shomura 1955). Males begin to dominate the catch from about 122 cm. (approximately 85 pounds), and this difference in sex ratios appears to increase with size (Fig. 1).

Assuming that there are no differences in the behavioral patterns of males and females, the disproportionate sex ratios among the large fish could result from (1) differential growth between sexes, (2) differential natural mortality between sexes, or (3) a combination of differential growth and natural mortality. The growth of bigeye and the differences in growth rate between males and females are investigated in the present paper.

## 2 METHODS AND MATERIALS

A sampling program was initiated in April 1960 to collect catch, effort, size, and sex data on the various tunas taken by the Hawaiian longline fishery. This fishery is the only one in the United States presently catching the large tunas by the set hook-and-line method developed by the Japanese. Details of the fishery are given by June (1950) and Otsu (1954). Since the fishery is dependent upon the fresh fish market, the catch is stored in ice and trips are of short duration, each trip averaging about 9 to 10 days (Shomura 1959).

The size and sex data for bigeye tuna collected from April 1960 through March 1961 form the basis of this report. The procedures followed in handling the data were:

(1) The data were summarized by grouping individual fish weights into 5-pound-class categories by month;

(2) Normal curves were fitted to the monthly weight distributions by the probability paper method (Harding 1949, Cassie 1954);

(3) A composite figure was constructed by combining the modal groups to represent a single "year-class";

(4) The asymptotic size calculated by using the Walford (1946) transformation was taken as a starting point in fitting a von Bertalanffy growth equation (Beverton and Holt 1957) to the data.

## 3 RESULTS

The monthly weight distributions of male and female bigeye (Fig. 2) show a number of overlapping modal groups. By separating the sexes and by utilizing the probability paper method we have been able to separate four to seven modal groups. Previous studies (Iversen 1955, Kamimura and Honma 1953) have been limited to a maximum of four modal groups. The regular occurrence of the modal groups in the present study is evidence that they are real and not vagaries of sampling. Nearly all of the modal groups can be followed throughout the entire 12-month period.

In order to describe the growth of males and females and to compare their growth rates over a period longer than 12 months several assumptions were made in constructing the composite figure (Fig. 3). These assumptions and the evidence available to support them are:

(1) That the modal groups represent year-classes. This is substantiated by the progression in mean size of the modal groups with time, which is such that the mean size of a modal group is approximated by the succeeding modal group 1 year later.

(2) That there are no differences in growth rate between year-classes.

(3) That the peak spawning occurs in April. Evidence supporting an early spring spawning is the capture of several bigeye with ovaries in the late stages of maturation early in the spring of 1961.

(4) That fish entering the longline fishery as recruits in September at about 45 pounds are 17 months old.

Although there are instances of an apparent cessation in growth (modal group D, females, April-July, Fig. 2) and even an apparent "negative" growth (modal group E, females, April-July, Fig. 2), the general increase in mean size over the 5-year period (age 2 to 7,

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Fig. 1 Length frequency distributions of bigeye tuna from 137°-165° E. longitude taken between March 29 and May 28, 1951 (adapted from Iversen 1955)

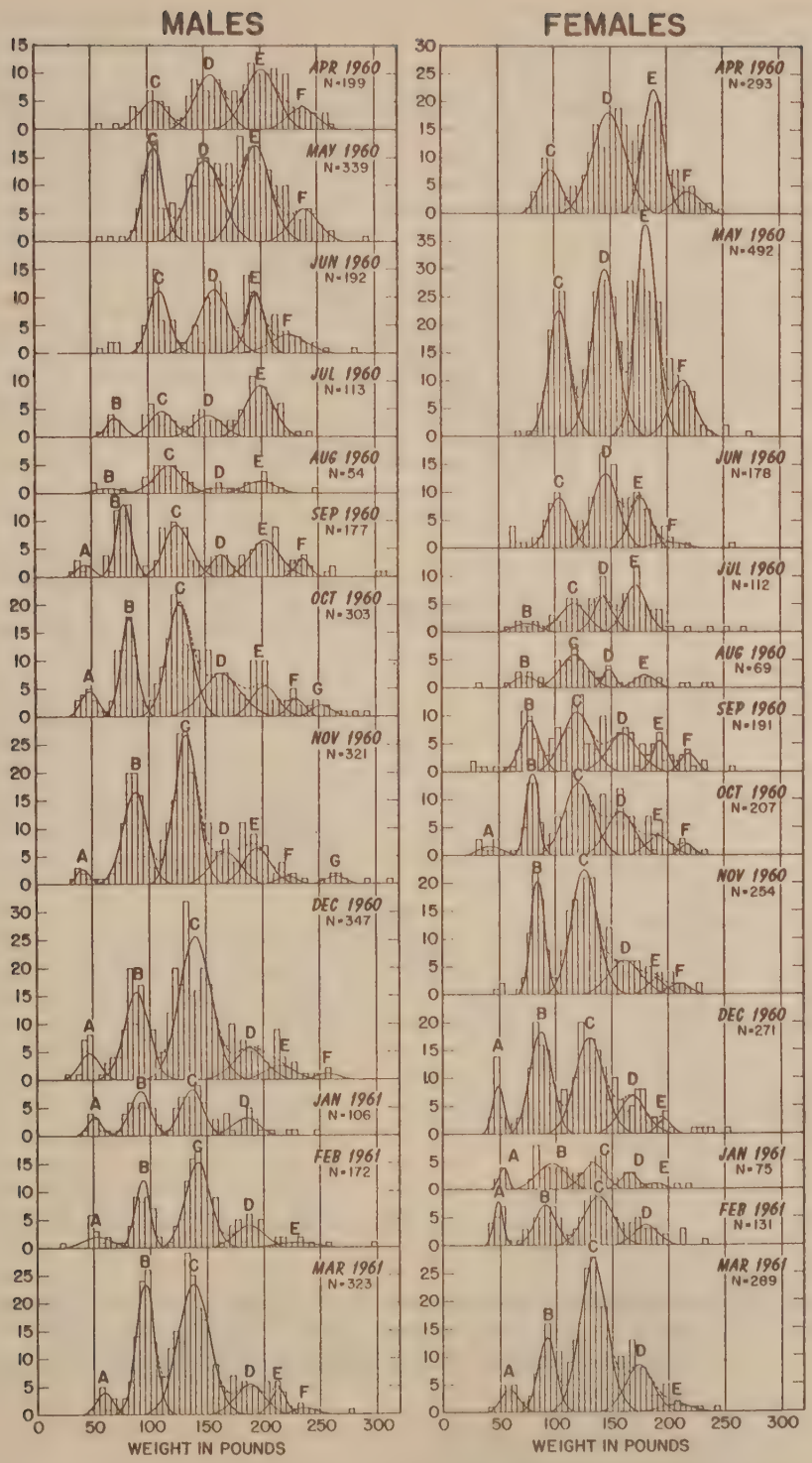


**Fig. 2** Monthly weight distribution of male and female bigeye, April 1960 - March 1961

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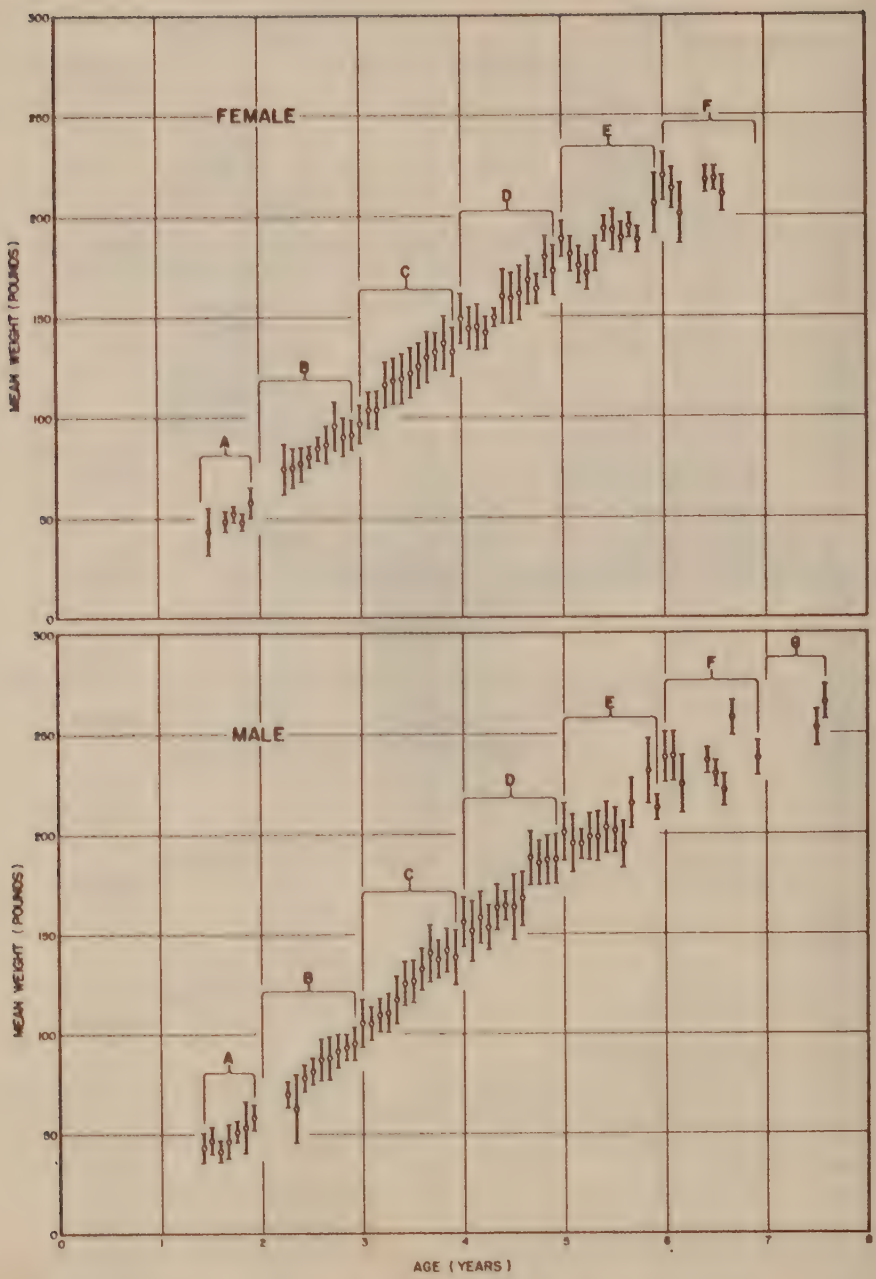


Fig. 3 A composite representation of bigeye growth. Upper panel - females, lower panel - males. Circles indicate means, heavy black lines span one standard deviation

Fig. 3) shows a growth of 200 pounds for the males and 175 pounds for the females.

A growth equation developed by von Bertalanffy was used to describe the growth of bigeye. The relationship of the growth parameters in this equation is:

$$W_t = W_\infty (1 - e^{-K(t - t_o)})$$

where:

- $W_t$ is the size (weight in pounds) of fish at time $t$
- $W_\infty$ is the asymptotic size (size at $t_\infty$)
- $K$ represents a constant which is proportional to the rate of metabolism
- $t_o$ is the hypothetical age at which the fish would have been zero pounds if it followed the growth rate as described for later life

Only modal groups B through F were used in fitting the von Bertalanffy equation. Modal group A was eliminated because these fish are being recruited into the fishery and the calculated mean size is probably not representative of the true value for this modal group. Modal group G was eliminated because of its sporadic occurrence and the small sample size.

The values of $W_\infty$, K, and $t_o$ for male and female bigeye are given in Table I, and the calculated growth curves are shown in Fig. 4. The growth rates for both sexes are similar up to about 100 pounds (Table II, Fig. 4). This similarity in the early years is also indicated by the closeness of the $t_o$ values (Table I). After age 3, the males grow faster than the females, and by the 7th year males are 25 pounds larger than females. The theoretical difference in weight is quite considerable for fish approaching the asymptotic sizes (518 pounds for males and 364 pounds for females), however, bigeye of these sizes have not been reported. Of about 6,000 bigeye sizes recorded from the central Pacific only 15 were found to be larger than 300 pounds. Thirteen of these fish were sexed and all were found to be males. The largest on record in our laboratory files is a 375 pound male.

Table I

Estimates of growth parameters for male and female bigeye

| | $W_\infty$ | $t_o$ | K |
|---|---|---|---|
| ♂ | 517.8 | 1.07 | 0.114 |
| ♀ | 363.9 | 1.06 | 0.167 |

Table II

Weight at age of bigeye tuna as determined from von Bertalanffy's equation

| | Weight (lbs.) | |
|---|---|---|
| Age (yrs.) | ♂ | ♀ |
| 1.5 | 24.9 | 25.5 |
| 2.0 | 52.3 | 52.8 |
| 2.5 | 77.7 | 77.5 |
| 3.0 | 102.0 | 100.8 |
| 3.5 | 125.3 | 121.5 |
| 4.0 | 147.1 | 141.2 |
| 4.5 | 167.8 | 159.0 |
| 5.0 | 186.9 | 175.4 |
| 5.5 | 205.1 | 190.3 |
| 6.0 | 222.7 | 204.5 |
| 6.5 | 239.2 | 217.3 |
| 7.0 | 254.2 | 228.9 |

## 4 DISCUSSION

Although the present evidence supports the hypothesis of sexual dimorphism in the growth of bigeye, growth alone does not explain all of the differences noted in the size and sex distribution. Differential mortality rates may be a complicating factor. The evidence for this is (1) that the sex ratios in the smaller sizes do not show a predominance of females, and (2) the presence of an apparent "negative" growth.

## 5 SUMMARY

Size and sex data of bigeye tuna collected from April 1960 through March 1961 from the Hawaiian longline fishery were utilized in a study of growth and sexual dimorphism in the growth of bigeye tuna.

From four to seven modal groups were defined from each monthly weight summary by fitting normal curves to the multi-modal distributions. The probability paper method was used to fit the normal curves.

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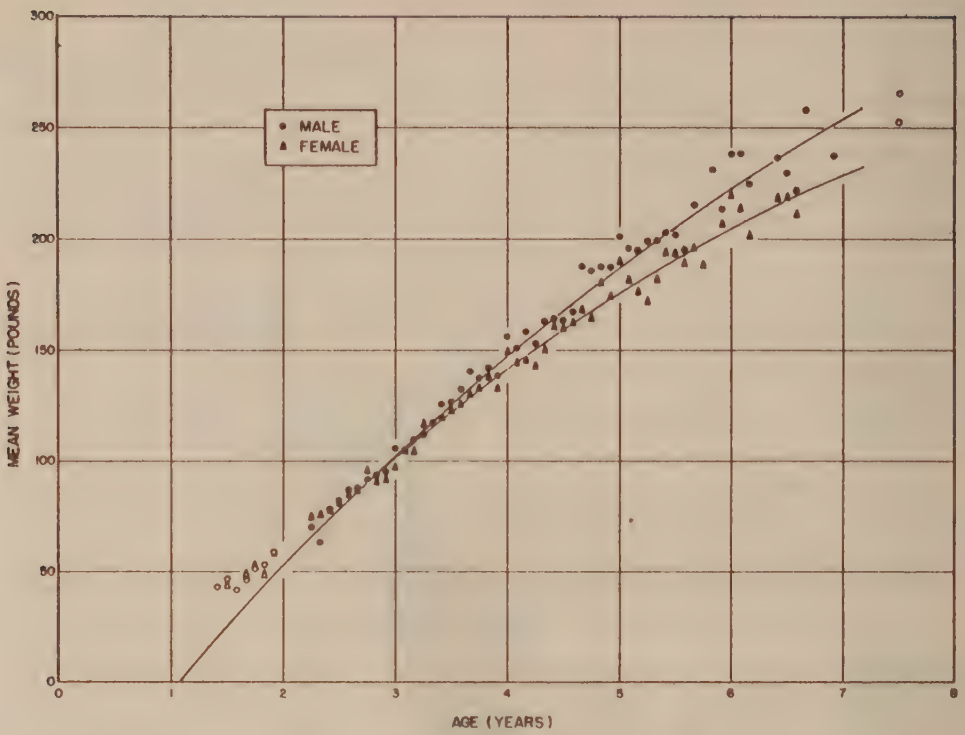


Fig. 4 A comparison of growth of male and female bigeye from Hawaiian waters, as calculated by the von Bertalanffy equation. (The points marked with open symbols were not used in the calculation of the growth curves.)

A composite figure was constructed showing the calculated mean sizes of male and female bigeye from ages 3 to 7. Males grew more rapidly than females after age 3.

The von Bertalanffy growth equation was fitted to the data. The parameters of the equation are: $W_\infty = 518$, $K = 0.114$, $t_o = 1.07$ for the males and $W_\infty = 364$, $K = 0.167$, $t_o = 1.06$ for the females.

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# BATHYMETRY IN THE GALÁPAGOS REGION *

George Shumway
*U. S. Navy Electronics Laboratory*
*San Diego, California*
and
Thomas E. Chase
*U. S. Bureau of Commercial Fisheries*
*Biological Laboratory*
*San Diego, California*

Most of the bathymetric data presented here are from expeditions of Scripps Institution of Oceanography, based on sounding lines obtained while crossing the region during the course of other work (fig. 1). Especially useful sounding lines were obtained by Scripps expeditions SHELLBACK, DOLPHIN, STEP-I, RISEPAC, and SWAN-SONG. Additional sounding lines have come from U.S. Navy ships participating in HIJUMP expedition. U.S. Navy Hydrographic Office chart 1798 contains a number of isolated soundings in the vicinity of the islands which also were included. Because available data are not abundant and sounding information is randomly located, the charts presented here must be considered only a preliminary synthesis.

On all expeditions of Scripps Institution of Oceanography, echo soundings were obtained with AN/UQ-1 echo sounders and were recorded on Precision Depth Recorders (except SHELLBACK, made before PDR's were used). The acoustic soundings were made with the assumption of an average sound speed in sea water of 4800 ft/sec. Corrections for true water sound speed have not been made.

The remoteness of the Galápagos Islands from the important world trade routes and the incomplete status of the mapping of the ocean floors have left the bathymetry of the Galápagos region relatively unknown up to the present time. In the past decade sufficient data have accumulated to construct the charts presented here (figs. 2, 3, 5, 6, 7). A series of charts of the eastern tropical Pacific including the Galápagos region is being prepared by the U.S. Bureau of Commercial Fisheries and the Institute of Marine Resources, University of California.

* Presented at the TENTH PACIFIC SCIENCE CONGRESS of the Pacific Science Association, held at the University of Hawaii, Honolulu, Hawaii, U.S.A., 21 August to 6 September 1961, and sponsored by the NATIONAL ACADEMY OF SCIENCES, BERNICE PAUAHI BISHOP MUSEUM, and the UNIVERSITY OF HAWAII.

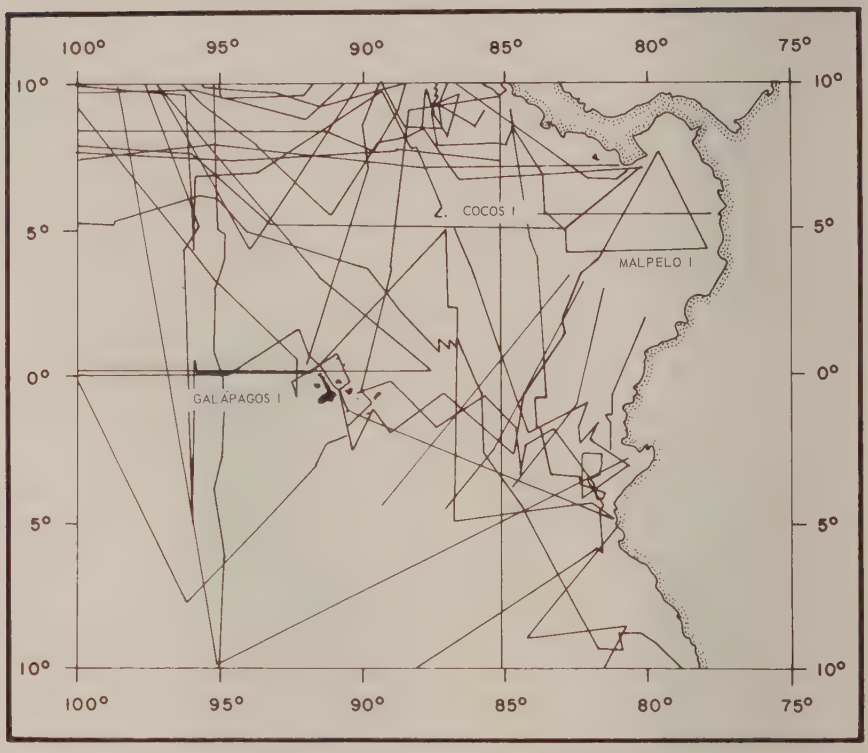


Figure 1. Sounding lines in the east equatorial Pacific Ocean, from Scripps Institution of Oceanography and U. S. Navy cruises.

## Regional Setting

The Galápagos Islands are a group of typical Pacific Basin basaltic volcanoes (MacDonald, 1949) about which there is little petrographic information. The volcanoes do not rise directly from the deep sea floor, but are perched on a platform elevated a thousand fathoms or more above the surrounding deep sea floor. This platform connects through a saddle on the east with the Carnegie Ridge (Shumway, 1957), and on the north it joins Cocos Ridge (Shumway, 1954). Typical fracture zone topography (Menard, 1955a, 1955b, 1960; Menard and Fisher, 1958) extends westward from the vicinity of Darwin Island for more than a thousand miles.

In the past decade, largely through the efforts of H. W. Menard and R. L. Fisher of Scripps Institution of Oceanography, an overall picture of the bathymetry in the eastern Pacific Ocean has come to light. It reveals that the dominant topographic features, beyond the trenches at the continental margins,

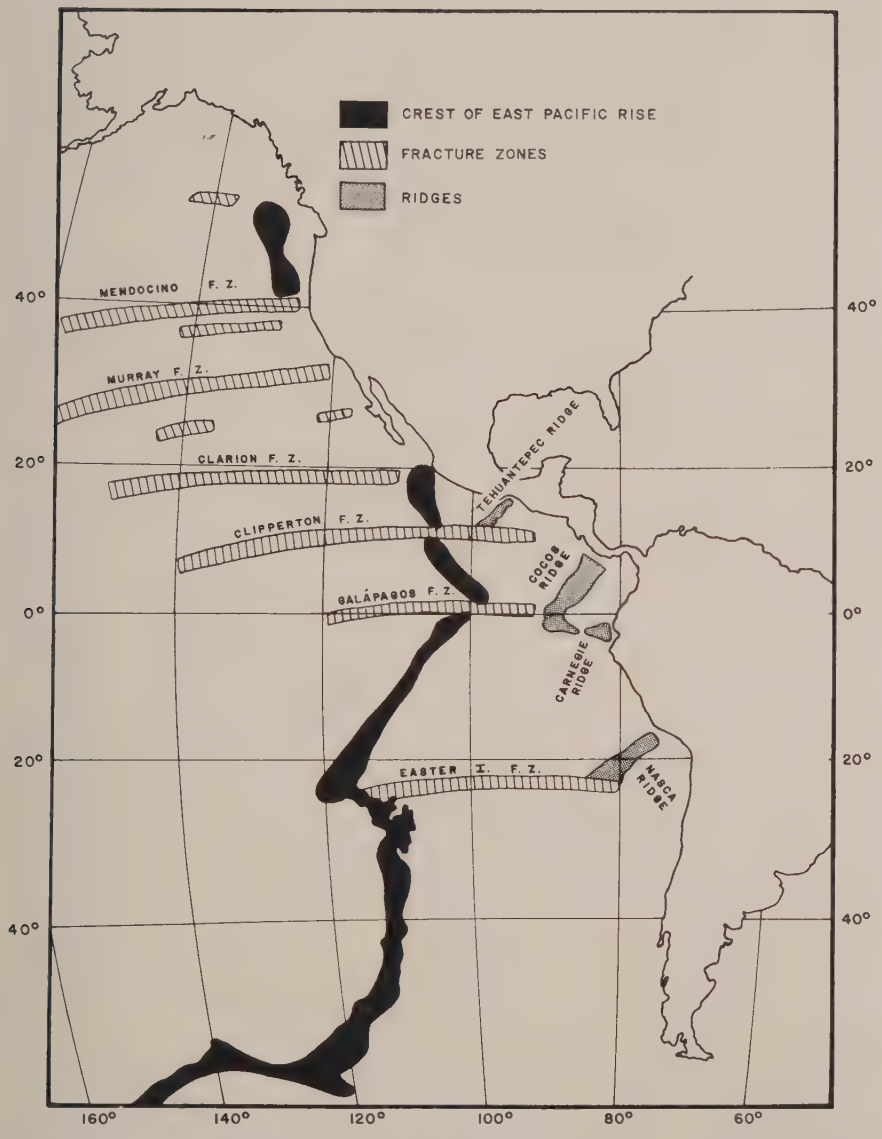


Figure 2. Crest of East Pacific Rise and location of East Pacific fracture zones (after Menard, 1960, modified).

are the East Pacific Rise, which is an elongated bulge of the sea floor extending from the vicinity of Antarctica to the Gulf of Alaska, and a series of fracture zones running westward from the continents for distances up to 3000

miles (fig. 2) (Menard, 1960). The Galápagos Islands are located on the eastern flank of the East Pacific Rise, and the Galápagos fracture zone cuts across the East Pacific Rise and apparently dies out on the western flank. The fact that Cocos Ridge meets the trend of the Galápagos fracture at an oblique angle does not seem to be unique, for the Clipperton fracture to the north has the Tehuantepec Ridge joining it obliquely, and the Easter fracture zone to the south has the Nasca Ridge joining it obliquely; all three ridges, Cocos, Tehuantepec, and Nasca have similar northeast-southwest trends. Thus the fracture zone and ridges associated with the Galápagos Islands are part of a regular system of topography in the eastern Pacific.

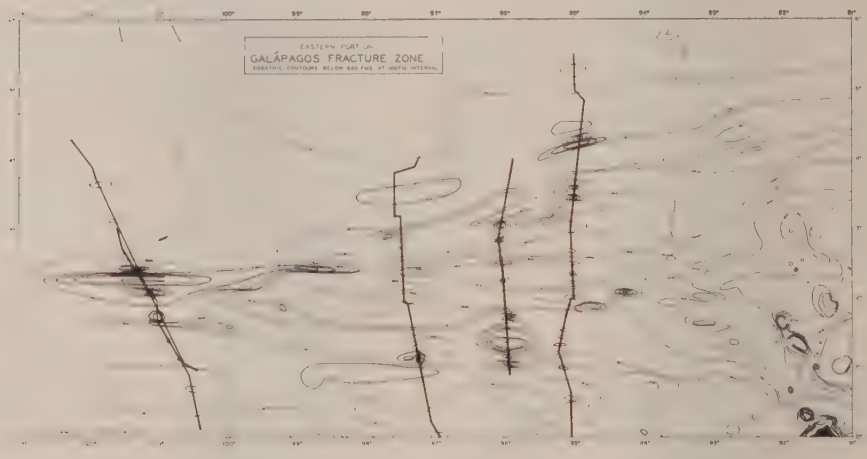


Figure 3. Eastern portion of Galápagos Fracture Zone, showing location of transverse profiles.

## Galápagos Fracture Zone

The existence of fracture zone topography west of Darwin Island was shown by Shumway (1954) on the basis of two echo sounding lines run across it by the SHELLBACK expedition; but when his manuscript was written in 1953, fracture zones had not assumed the importance geologically they now have. The matter was not pursued further at that time. Menard (1955) mentioned that on the basis of the limited information then available, a fracture zone running west from the region of the Galápagos Islands probably existed. By 1960 with more data available, Menard (1960) included a fracture zone in the vicinity of the Galápagos Islands on his bathymetric chart of the Pacific Ocean.

The following description of the Galápagos fracture zone is preliminary and is based upon soundings obtained through 1961. These data consist pri-

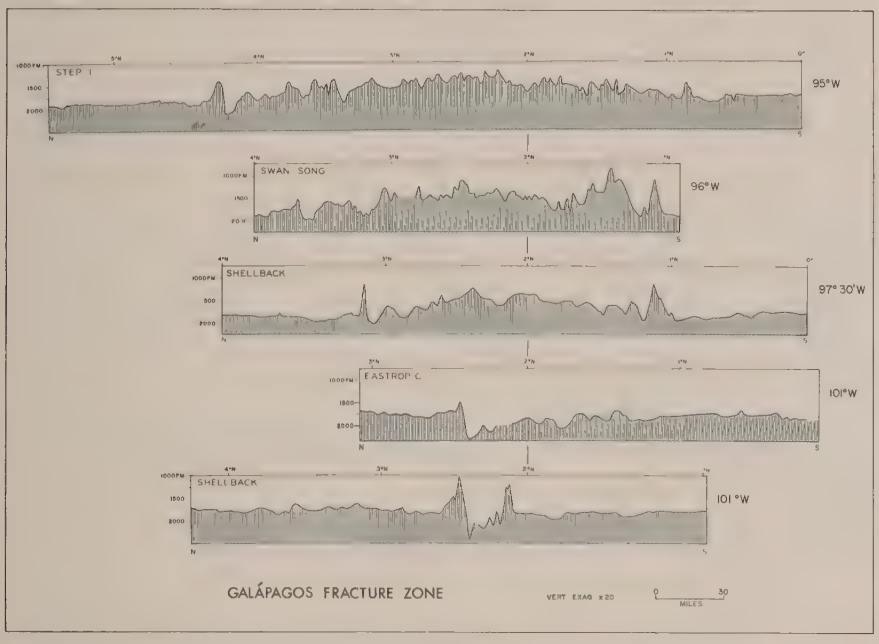


Figure 4. Transverse profiles across eastern portion of Galápagos Fracture Zone.

marily of transverse crossings of the zone. Large areas remain to be surveyed to ascertain the continuity of east-west trending ridges, troughs, and other structures (figs. 3, 4).

For the sake of explicitness we refer to the zone of irregular topography running west from Darwin Island as the Galápagos fracture zone, and retain the established names Cocos Ridge and Carnegie Ridge for the related structures to the east. This does not imply that the variously named features are structurally separate entities. Rather, it is probable that these features are structurally related and that they are part of the fracture zone.

## Galápagos Platform

The volcanic islands of the Galápagos are perched on top of a platform whose top lies a thousand fathoms or more above the deep sea floor to the south (fig. 5). It does not seem appropriate to call this feature a ridge, for at the 700 fathom isobath it has a length of 270 sea-miles and a width of about 100 sea-miles, and isobathic contours along its southwestern slope have a marked convexity.

To the east, the platform connects through a saddle with the western end of the Carnegie Ridge (figure 6 (Shumway, 1957). The low point of the saddle lies between 1200 fathoms and 1300 fathoms.

Figure 5. Bathymetry in the vicinity of Galápagos Islands.

On the south, southwest, and west sides, the Galápagos platform drops steeply to the deep-sea floor at more than 1800 fathoms depth. On the southwest side there is an elongate depression about 200 fathoms deeper than the sea floor farther to the southwest (fig. 5). Similar marginal depressions often are present around large seamounts, and a notable depression is found along the eastern and northeastern sides of the Hawaiian Ridge (Hamilton, 1957). The steep side of the platform lies close to the west and southwest sides of Fernandina Island and Isabella Island, with depths of 1700 fathoms being found within 6 or 8 sea-miles of the islands.

On the northeast side of the platform the bottom drops off gradually toward the Panama Basin without complications. On the north and northwest sides, however, the topography is complex; it is in this region that the fracture zone, Galápagos platform, and Cocos Ridge meet (figs. 3, 5, 7). Unfortunately, not enough sounding data are available to allow the complex topography to be resolved in the detail desirable.

A tongue of relatively deep water, i.e. greater than 1400 fathoms, lies between the north end of Isabella Island, Pinta Island, and Marchena Island. Darwin Island and Wolf Island are isolated from the Galápagos platform by about 60 sea-miles of water deeper than 1200 fathoms; in this respect they are not part of the Galápagos group.

The upper surface of the Galápagos platform contains numerous irregularities that cannot be contoured adequately on the basis of available sounding data. No attempt has been made to depict contours shoaler than 700 fath-

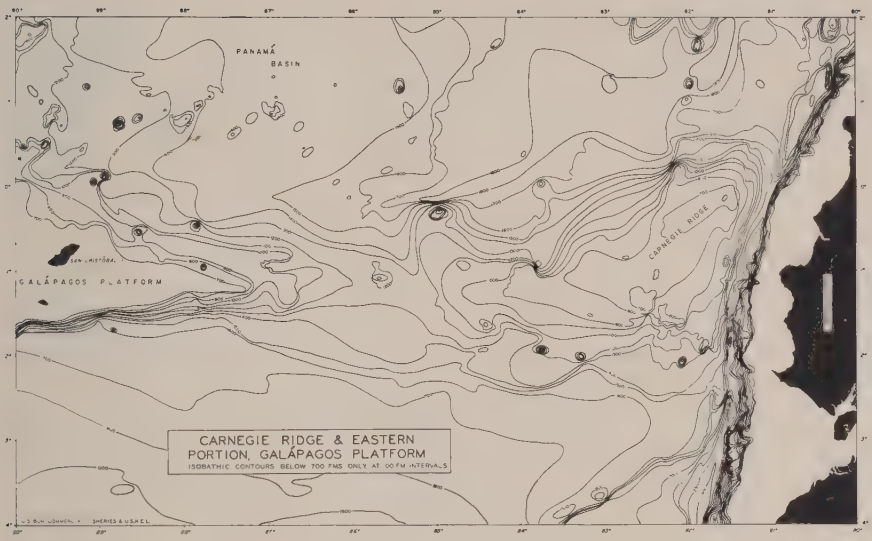


Figure 6. Bathymetry for Carnegie Ridge and the eastern end of the Galápagos Platform.

oms (fig. 5). A very detailed survey would be necessary to determine the inter-island bathymetry.

## Cocos Ridge

Cocos Ridge, running from the vicinity of Costa Rica to the region immediately north of the Galápagos Islands via Cocos Island was discussed by Shumway (1954). Since then additional sounding data which improve knowledge of the ridge have been obtained (fig. 7). Fisher's (1961) chart of the Middle America Trench shows that the northern end of Cocos Ridge is terminated by relatively deeper water at the eastern end of the Middle America Trench. The trench, however, does not extend east of the ridge. These facts suggest that the two structures have exerted some influence upon each other at their place of junction.

A favorably directed sounding line, running in an east-west direction at about 5° N. latitude, was obtained by Scripps Institution of Oceanography expedition DOLDRUMS. A bathymetric profile drawn from data obtained on this sounding line (fig. 8) reveals a domed central portion about 100 sea-miles in width flanked on the west by a steep escarpment about 500 fathoms high. To the east of the escarpment there is a steep-sided elevation, but apparently this is a local feature.

The data suggest that the northwest flank of Cocos Ridge may be a zone of particular crustal instability where repeated volcanic activity has created

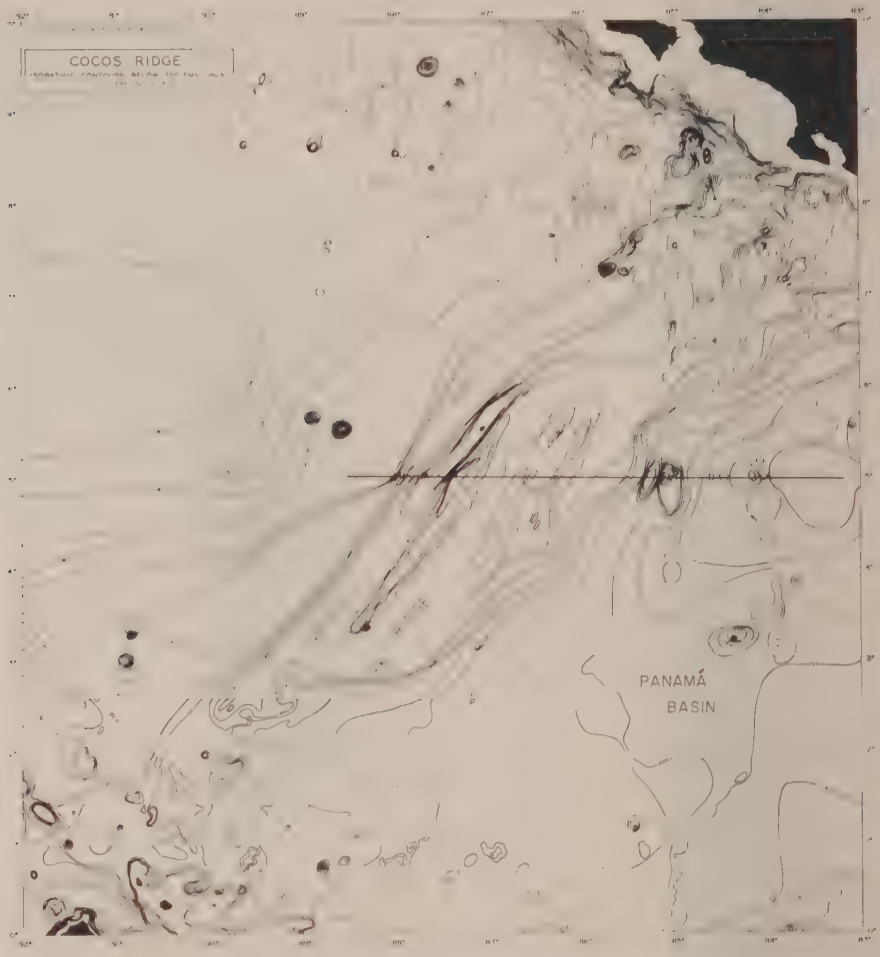


Figure 7. Bathymetry for Cocos Ridge.

a narrow ridge, portions of which rise higher than the main, central part of Cocos Island, is located along this northwestern flanking ridge.

## Summary

The Galápagos Islands rise from an elongated platform of eastwest trend which at the 700 fathom isobath is 270 sea-miles long and 100 sea-miles wide. South and west of this platform the sea floor drops steeply to depths greater than 1800 fathoms. The eastern end of the platform connects through a saddle with the Carnegie Ridge. On the northeast side of the platform the sea floor

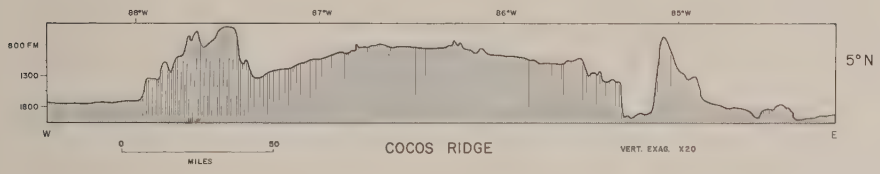


Figure 8. Bathymetric profile across Cocos Ridge along an east-west line at 5° N.

drops off gradually toward the Panamá Basin. To the north, the platform unites with the end of Cocos Ridge and with a fracture zone that extends westward from the vicinity of Darwin Island.

The fracture zone that extends almost due west from Darwin Island contains topographic features typical of the other fracture zones which parallel it to the north. This distinctive topography, with high narrow ridges adjacent to deep troughs, extends at least 600 sea-miles west of Darwin Island; the zone is less well defined farther west, but there is evidence of it as far as 1600 miles west of Darwin Island.

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# DISEASE IN MARINE POPULATIONS

Carl J. Sindermann

*U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine*

The possible importance of disease in marine populations of commercial significance has not been adequately explored. Only in recent years has more than sporadic attention been given to diseases of marine animals, and even now this attention is often restricted to periods of disease outbreak in a particular species. The value of marine disease investigations has been pointed out by Oppenheimer (1953), Oppenheimer and Kesteven (1953) and Mackin (1959), and it is evident that to derive maximum continuing benefits from the sea we must understand all aspects of the biological systems that underlie the harvest of marine products. Disease obviously constitutes one determinant of abundance.

Research on diseases and parasites of marine organisms has been carried on in several laboratories, including the Bureau of Commercial Fisheries Biological Laboratory at Boothbay Harbor, Maine. Emphasis at this laboratory has been on diseases and mortalities of Atlantic herring, (Scattergood, 1948; Sindermann and Scattergood, 1954; Sindermann, 1958), although other species such as redfish, smelts, oysters, snails, and lobsters have received attention (Sindermann, 1961b; Sindermann and Farrin, 1962). The present paper, based on published and unpublished results of our research and on published research of other laboratories concerned with disease in marine populations of the western North Atlantic, is designed to present evidence available to support the following general statements:

1. Disease is related to changes in abundance of marine organisms.
2. Disease outbreaks may be influenced by several factors, including changes in susceptibility of the host population.
3. Disease outbreaks in one species may have pronounced negative or positive effects on other species.
4. Some disease problems in the sea are amenable to solution.

## Epizootics in Marine Species

Most available information concerns epizootics—widespread or rapidly spreading disease outbreaks—which have variable effects on susceptible species. Some outbreaks have been severe enough to result in local extinctions, while others have had only transient effects on population size. Epizootics may vary in intensity in different species, for different pathogens, in different geographic areas or at

different times. The interactions of variables such as susceptibility of the host population, virulence and infectivity of the pathogen, effectiveness of transmission, and physical factors in the environment result in the dynamic changes in host-parasite relationship that we call an epizootic.

Possibly the most severe marine epizootic for which scientific information is available occurred in the late 1930's in velvet sponges and other sponges of the Gulf of Mexico (Galtsoff, 1940; Smith, 1941). Galtsoff reported that a fungus pathogen was responsible, but did not identify it. The outbreak led to extinction of velvet sponges in many areas of former abundance, and even today the populations of velvet sponges in parts of the Gulf have not recovered. Approaching the sponge epizootic in severity were mortalities of oysters on

Figure 1. Areas of oyster mortalities on the east coast of North America.

Prince Edward Island beginning in 1915 (Needler, 1947), and more recently on the northern New Brunswick coast and in Delaware Bay (Fig. 1.) . Mortalities in these areas exceeded 90 per cent, and spat derived from survivors were also decimated for a number of years. Although the causative agent was not determined, resistance was apparently developed in Prince Edward Island oyster stocks (Logie, 1956), but 10 to 15 years of apparently severe natural selection were required. Mortalities of oysters transplanted to the island from other areas many years after the epizootic demonstrated that the causative agent was still present (Logie, 1956, 1957; Drinnan and Medcof, 1961).

Of relatively moderate severity have been periodic outbreaks of a disease of Atlantic herring caused by the fungus *Ichthyosporidium hoferi*. Such outbreaks in western North Atlantic herring have been reported since 1898 (Cox, 1916; Fish, 1934; Scattergood, 1948; Leim, 1955); the most recent occurred in the Gulf of Saint Lawrence in 1954-55. The disease is systemic, with massive tissue invasion focusing

Figure 2. Normal (left) and fungus-infected herring hearts, with photomicrograph showing massive tissue invasion and disorganization.

in the heart (Fig. 2). Acute infection results in partial decay of the fish even before it dies. Mortalities due to this disease extended along hundreds of miles of Gulf of Saint Lawrence coastline in 1954 and 1955. An estimated one-half of the herring population in the Gulf was killed by the disease in those two years, and the reduction in landings since has supported our original estimate (Fig. 3). The disease decimated adult age groups and affected immature fish, but the high proportion of recruit spawners in 1960 and 1961—when herring spawned after the outbreak first entered the fishery—suggested that reduction in size of spawning stocks had not seriously

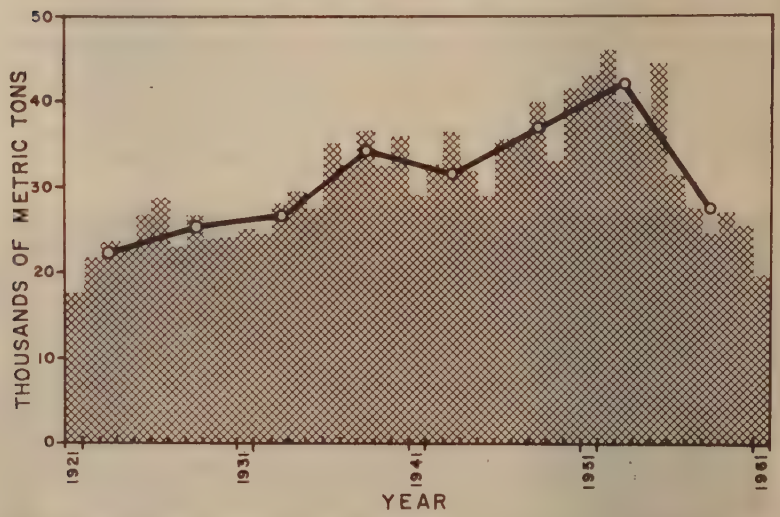


Figure 3. Gulf of Saint Lawrence herring landings 1921 through 1961, with five-year moving averages.

affected the size of year classes spawned after mortalities had ceased. The apparent periodic nature of outbreaks—14 to 25 years between peaks (Fig. 4)—indicates at best only transient increase in resistance of herring populations to the disease. This hypothesis is supported by the relatively low incidence of infections (27 per cent average at the epizootic peak—which constitutes relatively low selection pressure); by the fact that the most recent of four outbreaks in the Gulf of Saint Lawrence was at least as severe as the first; by determination of mortality rates during experimental epizootics in laboratory populations (Sindermann, 1958); and by experimental findings of individual variations in susceptibility to the disease.

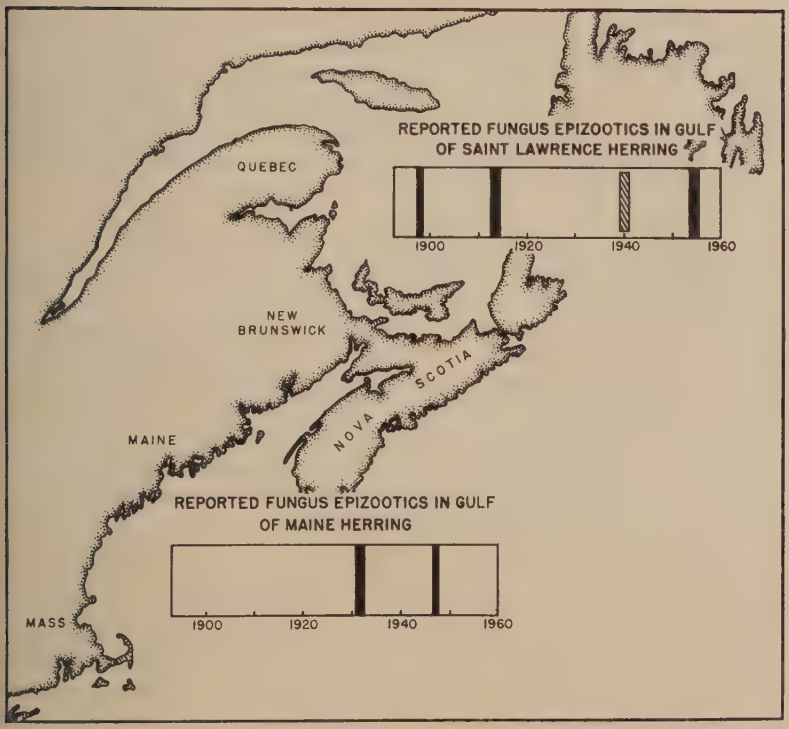


Figure 4. Reported fungus disease outbreaks in herring of the western North Atlantic. The Gulf of Saint Lawrence epizootic which occurred about 1940 was not recorded in scientific literature, and is included here on the strength of verbal reports from fishermen and other residents of the area. Such descriptions of the outbreak suggest that it was less severe than the 1954-55 epizootic.

Marine diseases with slight impact on abundance of a species are easier to find. An example is the protozoan disease of immature Atlantic herring caused by *Kudoa clupeidae*, a myxosporidian that produces intramuscular cysts (Sindermann, 1957, 1961a). The disease is acquired only in the early months of life, and symptoms disappear by the end of the third year of life. All degrees of infection may be found, but even heavily infected fish are present in schools containing mostly uninfected individuals. No differential mortality of infected herring occurred in laboratory experiments (Sindermann, 1957) and percentage of heavy infections remained unchanged in natural populations between the first and second years of life—an unlikely situation if differential mortality of heavily infected individ-

uals occurred. Unobserved mortality could occur in the early invasive stage of the disease, however.

These few examples illustrate the range of disease effects on marine species—from one extreme of virulent, widespread disease with extensive mortalities and local extinctions, to the other extreme of low endemicity and slight pathogenicity, with little or no mortality directly attributable to the disease.

## MEDIATING FACTORS IN MARINE DISEASE OUTBREAKS

Epizootic disease may be influenced by a number of often interacting factors, including:

1. *A population explosion of an introduced pathogen*—one to which the host species is susceptible and with which it has had little or no previous contact. Organisms in this category may be responsible for the severe oyster mortalities on our east coast—or the sponge mortalities off Florida. Also, such an epizootic in one species may result in an outbreak in other susceptible species occupying the same area. Sufficient infection pressure may be created to affect species less susceptible to the pathogen.

2. *Changes in the physical environment of the host population.* Effects of physical factors on disease outbreaks are difficult to determine in the marine environment, but have been clearly shown in fresh-water fish hatcheries, where furunculosis and other disease outbreaks have been influenced by temperature and chemical changes in the surrounding medium due to crowding (Davis, 1953; Snieszko, 1954, 1957, 1958). Disease susceptibility can be affected by such environmental variables as temperature, acting on antibody production; or availability of food, affecting the physiological condition of the host. Behavioral responses to seasonal environmental changes, such as major migrations, spawning, and inshore or offshore movements, could influence the spread of disease in a marine population. During the 1954-55 fungus disease outbreak in Gulf of Saint Lawrence herring, mortalities reached a peak in late spring, about one month after inshore spawning migration. Disease incidence was very low when fish first appeared on the coast in late April, and infections were probably acquired from spores overwintering in inshore sediments. Experimentally mortalities were produced in the same time interval (one month) following exposure to fungus spores.

Environmental factors can also operate more directly, such as temperature or salinity influencing the reproductive rate and infectivity of pathogens. In oyster mortality studies, salinities below about 15 parts per thousand retarded the development of lethal in-

fection levels of *Dermocystidium marinum* (Ray, 1954; Ray and Chandler, 1955). Mortalities caused by fungus were significantly higher in oysters maintained in higher salinities. Lower mortalities from this disease and decreased numbers of pathogens in live oysters were also noted during the cold months of the year. Mackin (1953) concluded that lower winter mortality resulted from decreased metabolic activity of *Dermocystidium.*

3. *Changes in virulence and infectivity of a pathogen already present in enzootic form in a population.* Some genetic change in the pathogen may drastically upset a previously existing relatively stable equilibrium situation with the host. Although no documentation exists in fishery literature, we have examples of this in the history of great human epidemics.

4. *Changes in effectiveness of transmission of the pathogen.* With fish as well as other animals, the development of epizootics may be influenced by relative effectiveness of transfer of the disease organism from one susceptible host to another. Transmission may be enhanced by high population densities of susceptibles in the early phases of an outbreak, or retarded by low densities of susceptibles in the later phases. Immigration of susceptibles into a population or addition of susceptibles by reproduction can also act to enhance transfer of the pathogen.

5. *Changes in susceptibility of the host population to an enzootic disease.* During a period of low disease incidence the numbers of susceptibles could be increased, since there is little selection pressure against susceptibility. A critical point is reached where the pathogen, always present in the population, begins to spread. Incidence and infection pressure increase as contacts between susceptibles and pathogens are enhanced. Incidence reaches a maximum during the epizootic peak and then decreases rapidly as susceptibles become relatively rare and opportunity for effective contact of susceptible and pathogen decreases.

Although other factors such as population density or changes in the physical environment may be important, fluctuations in susceptibility could account for the changes in incidence and intensity of infections (Fig. 5), and the periodic outbreaks of disease in Atlantic herring. From observations made before, during and after the three most recent outbreaks—1931, 1947 and 1954—the general sequence of events that has emerged includes a long enzootic phase of very low disease incidence, several years of rapidly increasing incidence, the epizootic peak, and several years of rapidly declining incidence, returning to the enzootic condition. The 1947 outbreak in Gulf of Maine herring occurred during a time of low incidence in the Gulf of

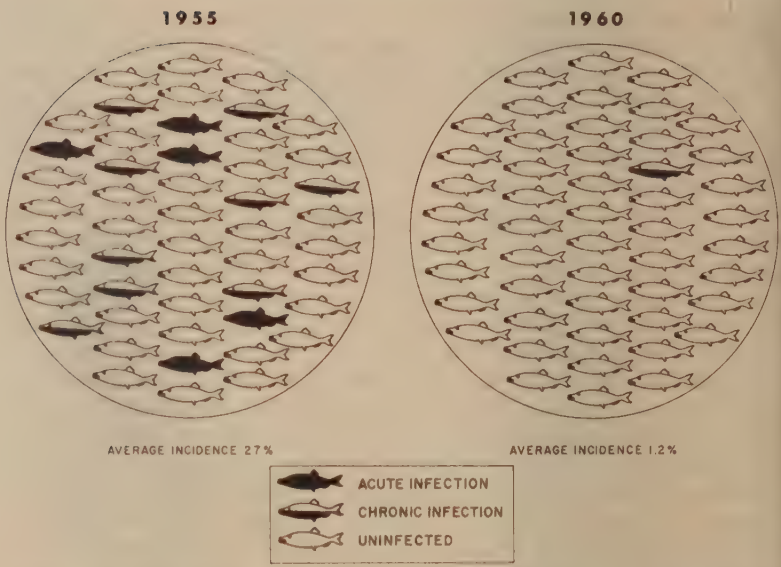


Figure 5. Relative frequencies of infected individuals in samples from Gulf of Saint Lawrence herring populations taken in an epizootic year (1955) and a post-epizootic year (1960).

Saint Lawrence, while the 1954 outbreak in Gulf of Saint Lawrence herring occurred when incidence was low in the Gulf of Maine. Continuing examinations for incidences of particular diseases in marine species have rarely been made. Periods for other diseases in other species could exist, but some may be much longer, so that two outbreaks of the same disease may not have occurred during the time when scientific study would have been carried out. Also, there seems to be a curious, and possibly more than coincidental, synchronization of outbreaks in different species due to different and unrelated pathogens. The underlying reasons, extrinsic or intrinsic to the species concerned, are obscure, but major outbreaks in several species have often occurred simultaneously. Prince Edward Island oyster mortalities in 1915, caused by an unknown pathogen, coincided with a fungus disease outbreak in herring; wasting disease of eelgrass (Renn 1934; Cottam, 1935) on the East Coast in the early 1930's coincided with a fungus disease outbreak in immature herring of the Gulf of Maine; lobster "red tail" disease outbreak in the Gulf of Maine, caused by a bacterium (Getchell, 1949), coincided with the 1947 fungus outbreak in herring of that gulf; and New Brunswick oyster mortalities of 1955 coincided with the most recent

fungus epizootic in herring of the Gulf of Saint Lawrence. Each outbreak or mortality was severe enough to warrant attention by itself, and could not have been noticed merely because of increased awareness of disease at the time.

### RELATIONSHIP OF DISEASE TO ABUNDANCE OF MARINE SPECIES

In the scientific literature there are several reports which definitely associate epizootic disease and mass mortalities with changes in abundance of marine species. The best evidence is found in the studies of herring fungus outbreaks. Cox (1916) reporting on the 1915 Gulf of Saint Lawrence outbreak, made this statement: "The herring fishery was reduced for several years following the outbreak." Similarly, herring landings in the Gulf of Saint Lawrence were reduced sharply following the most recent outbreak (1954-1955). Landings declined to slightly over half their previous level in the years immediately following the epizootic (Sindermann, 1958). The two most recent fungus outbreaks—the only ones for which we have adequate statistics from the fishery—occurred at times of herring abundance, as indicated by landing figures and general observations. Considering only two outbreaks, a relationship between epizootics and abundance might be coincidental, except for the obvious effect of disease on abundance of Gulf of Saint Lawrence herring in the late 1950's. Environmental factors other than disease undoubtedly influence abundance of herring, and an alternative explanation for the recent decline in the Newfoundland fishery was proposed by Olsen (1961). His explanation implicated a change in spawning habits, but failed to mention the extensive mass mortalities throughout the Gulf of Saint Lawrence, including the coast of Newfoundland, during the period 1954-1955.

Other evidence for causality of disease in population abundance changes can be seen in the Prince Edward Island oyster fishery following the 1914-15 outbreaks, the northern New Brunswick oyster fishery after 1955, and the Delaware Bay oyster fishery after 1958. In each area mortalities exceeded 90 per cent and persisted for several years. A weakness in this evidence is that a specific pathogen has not yet been related to mortalities, although a haplosporidian parasite has been implicated and the mortalities followed comparable patterns in the different areas. The effect, though, was clearly seen for each oyster growing area in the drastic slump in annual production that followed mortalities.

Apart from the conspicuous and sometimes catastrophic effects of epizootics on abundance of marine species, "low-level" or background disease effects may result in less conspicuous but not unim-

portant subtraction of individuals. Disease may be an important cause of mortality by weakening and disorienting infected fish, reducing their ability to survive changes in the physical environment and to escape predators; by making infected fish more conspicuous; or by altering their behavior patterns in ways that make them more vulnerable to predation. In our herring disease studies we have noted that fish with bacterial infections often exhibit characteristic and easily visible white patches near the tail (Fig. 6). Herring with fungus disease aggregate differentially in deeper water, and samples of immature herring from bottom trawls in inshore areas contain a higher frequency of abnormal fish than do samples taken with conventional surface gear in the same areas (Sindermann, unpublished observations). Among marine invertebrates, intertidal snails parasitized by larval trematodes do not participate in seasonal migrations to the same extent as normal individuals (Sindermann, 1960, 1961d). This has the effect of immobilizing diseased snails in the unfavorable high tide zone environment during winter months.

Disease may reduce the reproductive capacity of marine populations. Larval trematode invasion of marine snails such as the commercial periwinkle *Littorina littorea* causes sterility (Sindermann and Farrin, 1962). In inshore areas where such parasites are common, a significant percentage of individuals may thus be rendered non-reproductive. Gonad destruction has also been reported in crabs

Figure 6. Symptoms of "tail rot" in fish dead of bacteremia about five days from onset of symptoms.

as an outcome of parasitization by sacculinid copepods (Reinhard, 1942). Among the fishes, parasitic castration has been reported in European sardines (Pinto, 1956) by a sporozoan (*Eimeria sardinae*). The same parasite has been observed in male herring from the western North Atlantic (Sindermann, 1961c). Mechanical interference with discharge of sex products may result from massive infections of smelt by a microsporidian parasite, *Glugea hertwigi*. Visceral cysts containing spores may in heavy infections occlude the vent and occupy much of the posterior part of the body cavity (Haley, 1953; Sindermann, unpublished observations).

Diseases and parasites may also exert effects on mortality rate by slow continuous attrition. *Dermocystidium marinum*, a fungus parasite of oysters, often appears to act in this way (Ray, 1954; Ray and Chandler, 1955; Andrews and Hewatt, 1957), as does *Cryptocotyle lingua*, a larval trematode parasite of herring and other inshore marine fish.

### Effects of Disease Outbreaks on Other Species

An epizootic in one marine species may have pronounced negative or positive effects on related or associated species. The presence of great numbers of a pathogen during an epizootic may create sufficient infection pressure so that members of other species with less susceptibility to the disease organism may become infected. The presence of dying or disabled infected individuals may temporarily increase the food supply for predators or scavengers, resulting in accelerated growth and increased weight of such species. Evidence for such negative and positive effects of an epizootic in one fish species on other species was obtained from the fungus outbreak in Gulf of Saint Lawrence herring already mentioned above. Alewives, which seem less susceptible as a species to the fungus pathogen, (Sindermann and Scattergood, 1954) acquired infections and were killed in sufficient numbers to be observed. We examined one mass mortality at Dalhousie, New Brunswick in 1955, and others were reported by fishery officers and fishermen. Mackerel were also found to be heavily infected by the pathogen during the same period, and mortalities were observed. Cod, on the other hand, did not acquire infections, but fed on infected and dying herring to such an extent that their growth rate(indicated by scale growth zones) exceeded anything previously known (Martin, 1956). Cod landings almost doubled during the period immediately following the herring epizootic, due almost entirely to increased weight of individual fish landed, rather than to increased numbers of fish taken.

Other disturbances in the Gulf of Saint Lawrence fisheries

occurred at the time of the fungus disease outbreak in herring. Landings from the long-line fishery for cod on the Gaspe coast decreased drastically coincident with the onset of mass herring mortalities, while the trawled catches remained unchanged. The lobster fishery along the northern New Brunswick coast also suffered an almost immediate decline when herring mortalities began, probably because of the abundance of food outside the traps. Recovery of both the cod and lobster fisheries was rapid, however, in late summer and autumn, after the mass mortalities of herring had ceased (Sindermann, 1956).

Viewed in this way, disease outbreaks may be catastrophic to the host population, but temporarily quite beneficial to predator or scavenger species, some of which may have a higher unit value to man than the affected species.

## OTHER DISEASE PROBLEMS

Disease may be an important environmental factor at any stage in the life history of marine animals. Evidence from herring studies suggests this (Fig. 7), but evidence is particularly weak for the earliest life history stages where effects are apt to be most pronounced. Sizes of year classes are often determined very early in life—by relative survival of eggs, larvae, postlarvae, and juveniles. Eggs of marine fish are often coated with microorganisms, and Oppenheimer (1955) found that hatching percentages of sardine, flounder and cod eggs were increased in a bacteria-free medium. Fungi have been reported as parasites of crab and gastropod eggs (Atkins, 1929; Couch, 1942; Sandoz, *et al.*, 1944; Ganaros, 1957). Abnormalities, some of which may have been due to disease, were noted by Ahlstrom (1948) in up to 45 per cent of Pacific sardine eggs. Juvenile herring schools in their natural environment have been observed to contain individuals with bacterial tail rot (Sindermann and Rosenfield, 1954a) and in laboratory studies such infections have been found to be fatal within five days. These few examples suggest that disease effects on early life history stages of marine species can constitute a challenging area for future research, particularly that oriented toward understanding factors that determine abundance. While the success or failure of year classes may be influenced by many other environmental conditions, disease could play a major role in survival of early life history stages.

Another critical area of research concerns the effects of marine epizootics on the subsequent relationship of pathogen and host species. Varying degrees of selection pressure are exerted by epizootics, depending on their severity and duration. We have little

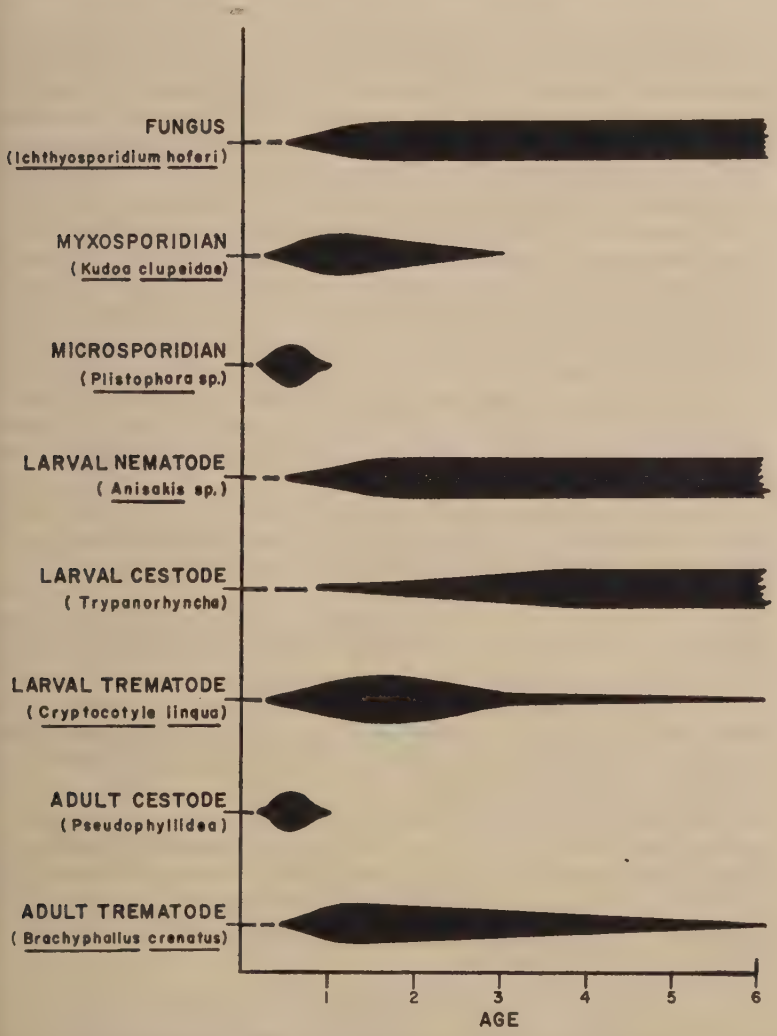


Figure 7. Relative abundance of diseases and parasites in herring of various ages. Dashes indicate lack of information.

information about the nature of resistance of marine organisms to disease—whether it be innate ("natural"), or acquired by previous exposure to a pathogen. Herring were found to vary individually in responses to massive experimental exposures to spores of the fun-

gus *Ichthyosporidium* (Sindermann, 1958). With identical spore dosages, some fish acquired acute infections and died within one month, some acquired subacute or chronic infections that persisted for as long as one and one-half years without killing the host, while some appeared uninfected, even after careful histological examination. Decreased incidences of acute infections were demonstrated in experimental groups of fish challenged by re-exposure to massive spore dosages, but attempts to demonstrate circulating antibodies by precipitin tests as well as hemolytic tests using tannic acid-treated antigen-coated erythrocytes were not successful. Four known epizootics have occurred in Gulf of Saint Lawrence herring, with no observable decrease in severity. On the other hand, information from study of Gulf of Saint Lawrence oyster mortalities which began in 1915 suggests that selection pressure was severe enough to cause a change in population susceptibility to an unknown pathogen. Oyster transplants from other areas were killed even many years after mortalities of native oysters had ceased. This indicated that the causative agent was still present, and that the surviving native stock was resistant, even though the nature of the resistance or, for that matter, of the pathogen, has not been demonstrated.

A final problem, especially acute in pelagic and other offshore fishery research, is that of observation of disease and the proper evaluation of its role. Diseased individuals may be consumed rapidly by predators, and fish dead from disease may be quickly disposed of by scavengers. Epizootics may come and go with no or almost no observations. Extensive mortalities may receive only sporadic examination, so that causative factors are usually not discovered, and the dimensions of disease impact on population size remain obscure. As an example, it is quite possible that the same fungus disease epizootics characteristic of Atlantic herring also occur in Pacific herring. Foerster (1941) and Tester (1942) reported herring and pilchard mortalities off Vancouver Island, British Columbia, with features remarkably like those observed during fungus outbreaks in Atlantic herring populations.

## AN APPROACH TO DISEASE CONTROL IN THE SEA

The original and persistent attitude toward disease in marine species has been that the environment imposes overwhelming obstacles to control or prevention of losses due to epizootics. There are, however, several things that can be done:

1. We can *understand* the ecological role and consequence of disease, in terms of abundance of commercial fish and shellfish species particularly, through continuous research.

2. Based on such understanding, we can hope to *predict* when outbreaks will occur. This would require continuous monitoring for changes in abundance of known pathogens, and for the appearance of new or previously unrecognized pathogens.

3. Finally, we can hope to *control* disease, particularly in inshore populations. With shellfish, control might take the form of development of disease-resistant strains. The natural environment seems to have successfully carried out the first phases of such an experiment in Prince Edward Island oysters. With inshore fish species such as herring, fungus disease control might take the form of actual addition of cultured spores to the sea, to artificially maintain the disease level at a point at which population resistance is continuously just high enough to prevent epizootics. Another approach might be deliberate overfishing of a population as soon as evidence of an incipient epizootic is discovered.

The fact remains that disease wastes protein that could be utilized by man. While natural checks on population growth and size are important for all species, the substitution of increased fishing mortality for decreases in certain parts of natural mortality of commercial species—such as that part caused by disease—could be important in the future.

## SUMMARY AND CONCLUSIONS

Of the natural factors that influence abundance of marine organisms, few are more spectacular or less understood than disease. Studies of diseases of marine animals have been carried on sporadically in recent decades, usually during times of epizootics in economically important species. Our information about the total role of disease in the sea is still incomplete, but evidence supporting certain generalizations has accumulated. In several studies, particularly those of Atlantic herring and oysters, epizootic disease has been related to changes in abundance of marine species. Disease outbreaks in one species have had pronounced positive or negative effects on other ecologically related species. Individual variations in susceptibility of marine organisms to particular pathogens have been demonstrated, and in at least one case a change in susceptibility of a population was indicated. Recent demonstration of specific immunological competence in fishes suggests that antibody response may be an important mechanism of resistance. Such findings indicate that the controlling factors involved in marine disease outbreaks are not fundamentally different from those underlying epizootics in terrestrial animals, and certain major fluctuations in abundance of commercial marine species may well have been related to disease.

Increased awareness of the role of disease in marine populations

has come from study of epizootics and mortalities in a few species of commercial importance. Pronounced effects on population size have been demonstrated, and it seems plausible that continued and expanded research will establish the importance of disease in the ecology of the sea. Disease has often and unrealistically been considered as a "constant" factor in determination of theoretical mortality rates for commercial species. Greater research commitment should provide a more factual basis for such analyses.

Research commitment and interest often expand and contract with disease incidence. We need stable long-term studies of causes and effects of epizootics. Epizootics and mortalities of oysters on the North American East Coast have probably received the greatest research effort, past and present, and serve as examples of the complexity of disease problems, even with sedentary inshore marine organisms. At least three pathogens have been implicated: *Dermocystidium marinum*, especially common in more southern areas; *Haplosporidium costale* recently described from Virginia (Wood and Andrews, 1962; Andrews, Wood and Hoese, 1962); and an undescribed haplosporidian (MSX), thought to play a role in recent extensive mortalities in Delaware and Chesapeake Bays (Andrews *et al., op. cit.*). Although advances have been made with descriptive and life-cycle studies, many gaps still exist in understanding of epizootics, transmission of pathogens, and susceptibility of hosts.

Those pathogens that have received most attention belong to an amorphous group variously assigned to the lower fungi or the poorly defined protozoan order Haplosporidia, (*Labrinthula* from eelgrass, *Dermocystidium marinum* from oysters, *Ichthyosoridium hoferi* from herring, *Haplosporidium costale* from oysters, an undescribed fungus from sponges, an undescribed haplosporidian (MSX) from oysters, to mention only a few). A few bacteria, such as *Gaffkya* of lobsters, have been identified as pathogens (Snieszko and Taylor, 1947), but to a large extent the role of bacteria and viruses as marine pathogens is incompletely understood. Facilities for recognition of viruses in marine organisms have usually not been available when mortalities have occurred. Some examinations for bacterial pathogens have been made during or after periods of mass mortalities, but reinfections from cultures have often failed or have not been attempted.

Here, then, is an area of marine research deserving of further exploration. Disease can be an important determinant of population size, whether the population be fish, oyster or sponge. If we are ever to understand the ecological systems that govern the yield of fishery products, we must scrutinize the maladies—epizootic and otherwise—to which marine populations are subject.

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## DISCUSSION

MR. FISHER: Not many years ago, one of the many Russian world-roving research vessels cruising in the Indian Ocean ran across an immense number of

floating dead fishes and a primary calculation by them was that that kill was equivalent to the total annual production of the world catch of fish. This is an area that is completely unexploited today in fishing. Whether or not the reason for the immense fish kill was determined—apparently it was a disease—the possibility of such phenomena on a similar scale in our own coastal waters points out the great need for study of diseases in fishes and other marine populations.

Thank you, very much, Dr. Sindermann, for this excellent and beautifully illustrated paper describing tremendous progress made in the very complex field of diseases.

One thing I would like to know is what tests are made in this kind of an infection, so that infected fish are not getting onto the market. I take it there is no particular toxic effect from these infected fish.

DR. SINDERMANN: Fish infected with the fungus organism definitely do get on the market. In fact, I was served infected fish on several occasions on the Gaspe Coast while we were studying the disease. Apparently, though, this is a disease confined to lower vertebrates and to invertebrates. We have done some experimental work with laboratory mammals, and have never been able to achieve infection by any possible route. It is found in a number of other fish species, and there are many interesting ecological aspects, but there seems to be no danger to humans from ingesting this material as far as our work with other experimental mammals is concerned. However, the Pure Food and Drugs people take a rather dim view of this organism, and this is one of the reasons why we have continued to study it, even though it is rendered, of course, incapable of any kind of infection by cooking. During the last outbreak in 1947, in the Gulf of Maine, some packs of sardines were seized because of the presence of fungus spores. This is a habit, I guess of the Pure Food and Drugs people, regardless of the nature of the fungus spore, that if the count exceeds a certain proportion, the particular lot is condemned. This occurred during that one year, and culling methods were immediately set up, but the disease declined into the post-epizootic phase in the following year. No further trouble resulted, but to the best of our knowledge, there is no danger to humans.

MR. MORTENOW [University of Michigan]: I think this is a very fine paper of wide adaptation for use in the study of bird populations. In birds, we frequently have epizootics and the numbers seldom exceed 10 per cent, and very rarely 20 per cent of the total population, and as a matter of an individual variation it renders the birds susceptible to death under these conditions, and it is of major interest to me. Can you give us any more information on the nature of the variations you have found and particularly their relation to birds?

DR. SINDERMANN: We have worked in the Gulf of Maine only with immature fish principally because this is about the only kind of fish that we get. Adults are further off shore, as a rule, and are not taken by the commercial fisheries, so our experimental epizootics were with immature fish, usually, too, with fish in their second or third year of life. We did find that below a certain level of spore dosage, all infections were sub-acute, and then beyond this point, we began getting increasing frequency of acute infections. These are rather sharply limited, although I expect there is a transition here, too. The acute infections are characterized by extensive necrosis without any great tissue response on the part of the individual fish, whereas the sub-acute or chronic infections which may persist in our tanks for up to 18 months are characterized by round cell infiltration, connective tissue incapsulation, pigment response immediately surrounding the spores, and so on, so that the two categories are reasonably distinct. These two persist at about one part of acute infection to two of chronic or sub-acute, and it is interesting to us that this is about what we found in populations of herring in nature taken in the Gulf of Saint Lawrence. The fishery up there is by gill net and tends to be non-selective, except that it does take adult fish. The timing of the epizootics is rather interesting, too, in that the fish come inshore about a month before they spawn, and apparently they acquire the infection as soon as they move in, from spores that we have been able to isolate from inshore

bottom sediments. They then begin dying at about one month, following the inshore movement, so that some of them, in fact many of them, probably have spawned before they are killed, at least in the first year, as we have a two-year epizootic period.

MRS. GRACE MURPHY: I am desperately interested in the effect of dredging on fish, and I cannot get as much data as I want. I am wondering if there are any permanent effects in both the offshore values and the harbors as well. Can you give me something on that subject?

DR. SINDERMANN: I am not sure that I can satisfy you very much. I have tried in my work with marine populations to take a fairly broad view, and about the only statement that I would care to make is that with most marine species, except for those that are strictly intertidal, man's effects are probably less important than natural phenomena. To me, predation and disease constitute the overwhelming environmental variables, and other factors are less important. Now, it can't be denied that in strictly inshore waters many of man's efforts have been deleterious to fish populations. As far as the offshore banks are concerned, I don't see how trawling—and I think you are referring to trawling—would have a serious total effect on the species except for those very limited banks that are gone over time and time again during the spawning season, and here, I am sure that some effect would be produced on the eggs, primarily those fish that have eggs that attach to the bottom.

DR. LONGHURST: I was wondering if you have any evidence that these diseases are in any way density connected?

DR. SINDERMANN: Insofar as the fishery is any indication of abundance of a marine species, and often it is a very poor indicator, there is some evidence that the past two epizootics, which were the two studied most intensively in '47 and '55, occurred in times of relative abundance of herring. This is probably the only detailed information we have, and this is not too detailed. We did notice, for example, that in the early 1950's, before this outbreak, herring were numerous enough in the Gulf of St. Lawrence that they were spread on fields as fertilizer, and in the post World War II years just preceding the 1947 outbreak in the Gulf of Maine, again herring were abundant enough so that catches in some cases could not be accepted by the processors. This might, of course, have been related to economic conditions, as well. So again, as far as data from the fishery gives us a clue about abundance, there does seem to be association of outbreaks with high density of population.

DR. GUSTAF SWANSON [Cornell University]: In this very fine paper, in referring to the epizootic and showing us the slides indicating incidence, I believe you used the term "periodicity." I would just like to comment on that because as I read those charts, I would use the term "neat irregularity" instead. Periodicity means recurring at regular intervals. It means being predictable, and I think we have been so oversold on the idea of cycles and periodicity that we conclude there is periodicity where it does not actually occur. We feel that these epizootics actually do periodically appear and almost can be predicted.

DR. SINDERMANN: We started out with our work on this disease with the idea that this was not a periodic thing, but evidence has accumulated to the point where if you don't like the word "period," some other, and possibly, "cyclic phenomena" would be in order. It's not perfectly regular, but when you look at the number of possible environmental variables that could influence this, I think it is not outside the realm of periodicity to have a range of maybe 10 years between epizootic peaks. Now, our earlier work in the Gulf of Maine showed two definite outbreaks. We had three in the Gulf of Saint Lawrence, and have recently come up with a fourth one there from rather obscure reports. If four outbreaks spaced roughly 15 to 25 years apart is not some evidence of a cyclic or roughly periodic phenomenon, then I think we will have to wait for one more. In fact, we are waiting for such an outbreak now in the Gulf of Maine. We are following both these gulfs every year in terms of incidence, and our picture, of course, won't be complete until we can carry these observations through an entire outbreak period. Our

practical reasons, of course, are obvious. We need, first of all, a prediction of when the next outbreak will occur, and I think we can get this. The last two outbreaks have been characterized by several years of increasing the incidence. We need also to think about controlling this thing, and I don't think this is outside the realm of possibility, either, but I won't argue with you about the disease periodicity, except to say that four outbreaks constitute, to me, evidence that something rather regular is going on.

IMMUNOGENETIC STUDIES OF ELASMOBRANCH FISHES. Carl J. Sindermann, U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine.

Systematic studies of marine vertebrates, particularly investigations of subpopulations. have been materially aided in recent years by application of immunogenetic techniques. The elasmobranch fishes were found in the present work to constitute excellent material for basic studies with blood grouping methods.

Erythrocyte antigens have been detected in spiny dogfish (Squalus acanthias) and big skates (Raja ocellata) with cross-matching tests and absorbed rabbit antisera. In dogfish, strong isoagglutinins distinguished an antigen designated $S_1$, while absorbed antisera distinguished a second antigen, $S_2$. Individual fish possessed both, either, or neither antigen. Comparative studies of gravid females and their unborn young indicated that the two antigens were part of the same blood group system. Two erythrocyte antigens have been demonstrated in big skates with isoagglutinins as well as with absorbed antiserum. Individual skate sera were found, with cross-matching and absorption analysis, to contain both, either, or neither isoagglutinin. Isoimmune antibodies with less specificity have been demonstrated one year after isoimmunization. Strong natural heteroagglutinins for teleost and human erythrocytes were found in big skate sera, and a year-round study indicated that titers varied seasonally, reaching a maximum in summer and a minimum in winter. Isoagglutinins have also been demonstrated in little skates (Raja erinacca), but have not been detected in thorny skates (Raja radiata) or in barn door skates (Raja laevis). However, both thorny and barn door skates possessed strong and specific heteroagglutinins for erythrocyte antigens of certain big skates and Atlantic herring (Clupea harengus).

The smaller elasmobranchs thus possess several desirable characteristics for immunogenetic studies. They are easily maintained in marine aquaria, possess clearly defined isoantigens and isoagglutinins, and many are ovoviviparous.

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# Electrophoretic Analysis of the Hemoglobins of Atlantic Clupeoid Fishes

CARL J. SINDERMANN AND KENNETH A. HONEY

# Electrophoretic Analysis of the Hemoglobins of Atlantic Clupeoid Fishes

Carl J. Sindermann and Kenneth A. Honey

**Hemoglobins of five species of Atlantic clupeoid fishes, analyzed by agar electrophoresis for possible variant patterns that could be used to determine discreteness of subpopulations, were remarkably similar in numbers and mobilities of fractions. No abnormal hemoglobin patterns were found in the samples examined. One species (Atlantic herring, *Clupea harengus)* was sampled throughout much of its area of abundance in the western North Atlantic Ocean, and at various ages and maturity conditions, without finding variant hemoglobin patterns.**

THE search for genetically determined factors in the blood of fishes which may be used to identify races or subpopulations has resulted in investigation of erythrocyte antigens, serum antigens, and hemoglobins. Geographic variations in frequencies of erythrocyte antigens have been reported for several fish species (Suzuki, Morio, and Mimoto, 1959; Sprague and Vrooman, 1962). Ridgway, Klontz, and Matsumoto (1962) found geographic variations in frequencies of certain serum antigens of salmon (*Oncorhynchus nerka*). Sick (1961) designated hemoglobin types for *Gadus merlangus* and *Gadus morrhua* and found geographic differences in frequencies of each type. Other electrophoretic analyses of fish hemoglobins have failed to disclose individual variations in the species studied (Buhler and Shanks, 1959; Chandrasekhar, 1959; Sick, Westergaard, and Frydenberg, 1962).

As an adjunct to serological studies of clupeoid fishes of the western North Atlantic Ocean being carried on at the U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine (Sindermann and Mairs, 1959; Sindermann, 1962), an electrophoretic analysis has been made of the hemoglobins of five major Atlantic coast clupeoid species: alewife, *Alosa pseudoharengus;* blueback herring, *Alosa aestivalis;* American shad, *Alosa sapidissima;* Atlantic herring, *Clupea harengus;* and Atlantic menhaden, *Brevoortia tyrannus.* Objectives of the study were to determine (1) whether individual variations in hemoglobin patterns exist in the species examined; (2) whether such physiological variables as age or condition of maturity exert any influence on electrophoretic characteristics; and (3) whether inferences about the taxonomic relationships of clupeoid fishes can be drawn from hemoglobin patterns.

## Methods

Blood samples were obtained from living fish by heart puncture with Pasteur pipettes. Blood was collected in tubes containing 6% citrate. Erythrocytes were washed three times in 1.5% saline, and hemolyzed with distilled water in proportion of one volume packed cells to two volumes distilled water. Hemolysates were refrigerated one hour and centrifuged; the clear supernatant hemoglobin solution was decanted and frozen at −20°C until tested (comparisons of fresh and frozen hemoglobins indicated that freezing and thawing had no observable effect on electrophoretic properties).

Electrophoresis of hemoglobins was carried out in agar with a modification of a method described by Giri (1956). The modified method is rapid (2 hr) and permits simultaneous electrophoresis of 12 samples. Thirty ml of 1.5% buffered agar (sodium barbital, *p*H 8.6, ionic strength 0.05) is poured on a glass plate (180 × 100 × 3 mm) to which a hollow rectangular plexiglass form with the same outer dimensions and thickness has been attached (Fig. 1A). Filter paper wicks (Whatman No. 1) 180 × 60 mm are inserted between plate and form before the agar is poured. Before the agar hardens, a plastic insertion slot former (Fig. 1B) is placed across the center of the form. The slot former is removed after the agar hardens leaving 12 slots 10 mm long, 0.5 mm wide, and 2 mm deep. The hemoglobin solution is added with a Pastéur pipette. The plexiglass form and agar are then covered with a second glass plate, and the filter paper wicks are in-

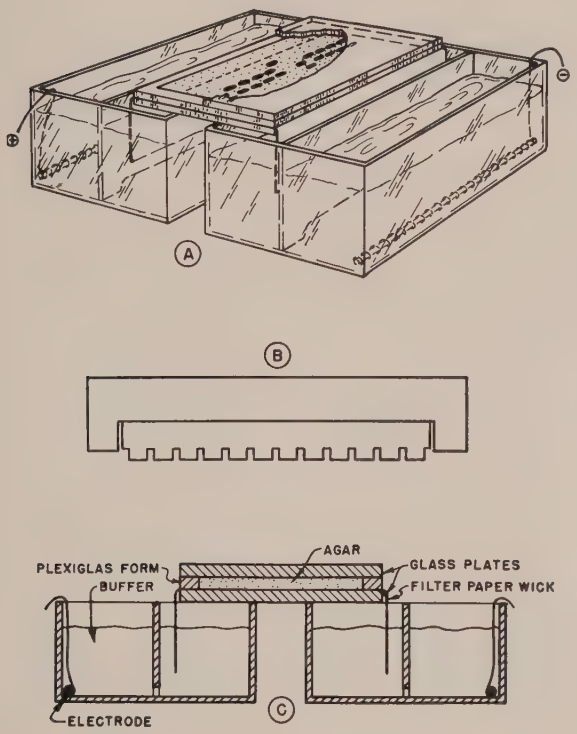


Fig. 1. Agar electrophoresis apparatus (modified from Giri, 1956). A, top view; B, insertion slot former; C, vertical section.

serted in chambers containing platinum electrodes and sodium barbital buffer of *p*H 8.6 and ionic strength 0.05 (Fig. 1C). Current is supplied from a regulated power supply (30 milliamperes at 200 to 300 volts) for 2 hr. A sample of human hemoglobin A is included with each test series, and serves as both control and standard.

Contact prints of hemoglobin patterns are made by placing the glass plate and agar containing hemoglobin bands immediately over a sheet of photographic paper. A permanent record of migration distance, as well as number and intensity of fractions, is thus obtained for each individual sample.

## Analyses

A single electrophoretic pattern characterized all five clupeoid species studied. Hemoglobins were composed of two clearly defined components, a broader, denser, but less mobile band and a narrower, faster-moving, less dense band (Fig. 2). Electrophoretic mobilities of the components were remarkably similar for all species examined, except American shad, where mobilities of both components were slightly greater than the other species. All fractions, including the human hemoglobin standard, moved toward the cathode under the experimental conditions and with the buffer used.

No significant individual variations were found in 25 samples each of alewife, American shad, Atlantic herring, and Atlantic menhaden collected at Belford, N. J., or in 6 samples of blueback herring from Georges Bank. A sample of hemoglobin from one alewife was unusual in that the less mobil fraction was very dense and the lead fraction reduced to a trace, but no differences were noted in number of bands or migration distances. A further sample of 100 alewives from Damariscotta Mills, Maine, disclosed no individual variations in electrophoretic patterns.

A series of 621 blood samples from Atlantic herring distributed geographically from New Jersey northward to the Gulf of St. Lawrence

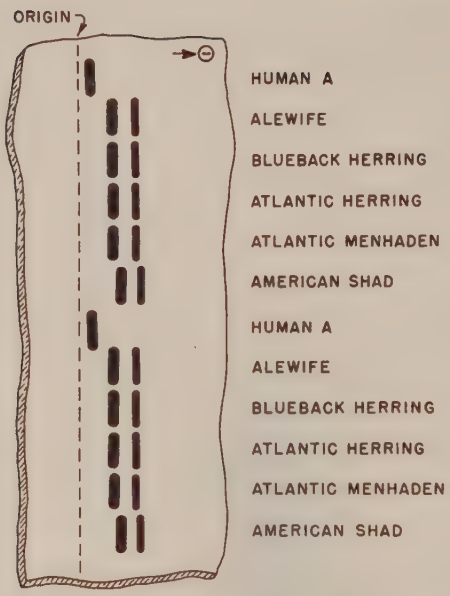


Fig. 2. Hemoglobin fractions, intensities, and relative migration distances of five clupeoid fishes, compared to human hemoglobin A. This diagram was redrawn from a contact print, using the agar plate as a negative.

(Fig. 3) disclosed no individual variations in hemoglobin patterns. Hemoglobin patterns of immature fish in their second year of life did not differ from those of adults four or more years old, nor did hemoglobins or prespawning adults differ from those of spent fish taken in the sames catches.

## Discussion

The present study has demonstrated essential similarity in electrophoretic properties of hemoglobins from five species of clupeoid fishes, and has not disclosed any variations that could be designated as hemoglobin types. However, conclusions about the existence of variant hemoglobin patterns in any species would depend on samples from the entire range of the species, since reproductively isolated subpopulations could contain or fail to contain variant hemoglobins, as has been demonstrated with human hemoglobin types (Jonxis and Delafresnaye, 1959; Pollitzer, *et al.*, 1959; Scott, *et al.*, 1959). More extensive sampling of some clupeoids considered in this paper might disclose variant hemoglobin patterns, although this was not true for Atlantic herring, when samples were obtained near the opposite ends of their range along the North American east coast (New Jersey

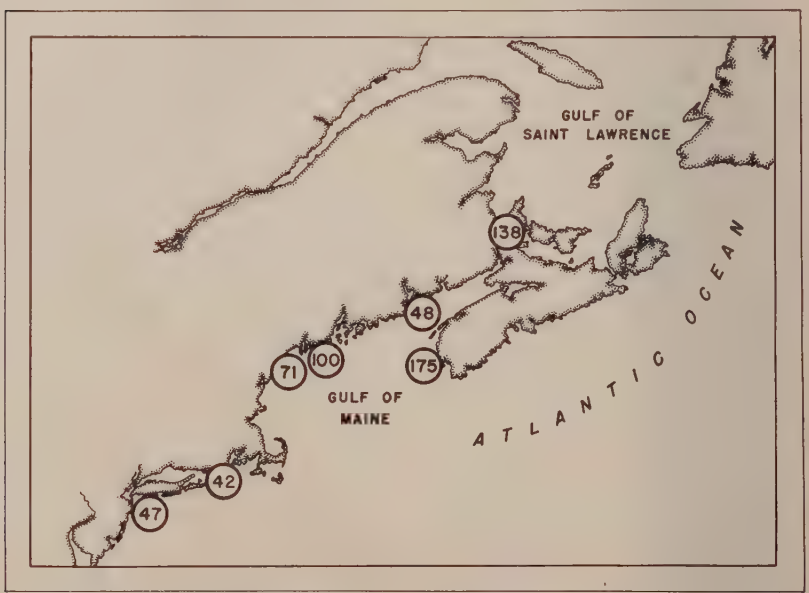


Fig. 3. Locations and numbers of blood samples from individual Atlantic herring used in hemoglobin analysis.

and Gulf of St. Lawrence) as well as in intermediate locations, nor for alewives sampled in two widely separated areas.

Sick (1961, p. 896) stated ". . . preliminary results suggest that haemoglobin polymorphism may be of rather common occurrence in fishes. . . ." Thus far hemoglobin polymorphism or intraspecific variation in hemoglobin electrophoretic patterns has been reported for only four teleost species (Sick, *op. cit.*). Intraspecific variations in hemoglobins have not been found in other fishes examined in quantity. This indicates that electrophoretic analysis of hemoglobins may be a useful approach to the recognition of subpopulations in certain species, but may in other species (such as the clupeoids) be of little utility.

Electrophoretic analysis of hemoglobins has provided no new information about the natural relationships of the clupeoid species studied—species which have distinct serological characteristics (Mairs and Sindermann, 1962). Patterns of all five species of clupeoids were very similar. This agrees with results of Bertini and Rathe (1962) in which hemoglobin patterns for several amphibian species in a genus or family were often identical.

## Summary and Conclusions

Electrophoretic analysis of the five principal species of western North Atlantic clupeoid fishes has disclosed a remarkably similar two-component pattern for all. Migration distances were identical except for American shad, where mobilities of the two components were only slightly greater than those of the other species.

No individual variations in numbers or mobilities of hemoglobin fractions were noted for any of the species examined. Atlantic herring were sampled throughout much of their area of abundance along the coast of North America, but no variant hemoglobin patterns were found. Other species were sampled principally on the New Jersey and Maine coasts, where no variant patterns were found.

Although more extensive sampling could disclose the existence of abnormal hemoglobins in the species studied, results obtained in the present work contrast with published findings of individual variability of erythrocyte antigens in these species. Lack of individual hemoglobin variability suggests that hemoglobin analyses will be of less utility to studies designed to identify races or subpopulations of clupeoid fishes of the western North Atlantic Ocean than investigations of blood group frequencies.

*Acknowledgment.*—The authors wish to acknowledge the technical assistance of Susan Cottrell.

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U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine.

Portland Press Herald State of Maine Edition June 29, 1963

# Initial Sardine Biology Research Results Termed Very Informative

## New Research Vessel To Cruise Gulf Of Maine Extensively

By BERNARD EINAR SKUD
Laboratory Director
U. S. Bureau of
Commercial Fisheries
Biological Laboratory
Boothbay Harbor

The U. S. Bureau of Commercial Fisheries Biological Laboratory at Boothbay Harbor has expanded its research activities on Maine sardines. Monies received last fall have been directed toards answering questions about sardine abundance which are of importance to the Sardine Industry.

The new funds will make it possible to conduct coastwide cruises on a regular basis; periodic offshore cruises; studies of commercial landings; wide-scale tagging experiments; and extensive laboratory tests. The need for this additional research has been evident for some time but was not fully appreciated until 1961, one of the poorest sardine seasons on record.

The Bureau's laboratory in Boothbay Harbor is one of four biological laboratories in the North Atlantic Region of the Bureau of Commercial Fisheries. The regional headquarters are in Gloucester, Mass. and the other biological laboratories are at Woods Hole, Mass.; Milford, Conn.; and Oxford, Md.

**Cooperative research programs** of these laboratories, such as the regional oceanography program, are designed to provide the most efficient use of research funds.

### CRUISE STUDIES

For example, the new research vessel, Albatross IV, of the Woods Hole laboratory will conduct extensive cruises in the Gulf of Maine and will provide the fishery scientists of the Boothbay Harbor laboratory with valuable information concerning the biology of herring — the species utilized in the Maine Sardine Industry.

Vessels utilized by the Boothbay Harbor laboratory include the Phalarope II, the Rorqual, and the Delaware. The cruises of these vessels represent an important facet of the expanded herring research program.

The vessels operate on a year-round basis, the Phalarope II in the area bounded by the Sheepscot and Damariscotta Rivers, and the Rorqual from Cape May to Grand Manan Island.

These cruises are designed to study the inshore habitat of larval herring. The objective of this study is to provide information which can be used to estimate the abundance of larval herring and to assess the importance of the environment to this species.

This intensified research program has been under way since last Sept., and the initial results have been very informative. Of particular importance has been the discovery that larval herring frequent the upstream waters of estuaries during the winter months.

Previous attempts to locate larvae at this time of year had been unsuccessful and their whereabouts was unknown until the spring of year when the young fish appeared in the surface waters of various bays along the Maine coast.

### SAMPLING PROGRAM

With this new knowledge, attemps will be made, through a systematic sampling program, to compare the larval abundance in the estuaries each year and to relate these findings to resultant catches of sardines six to 18 months later in the fishery.

Cruises with the Delaware have been conducted in offshore waters such as Georges Bank. This is the area where the Russian fishing fleet took 67,000 metric tons of adult herring in 1961. Utilizing the results of their previous research of Georges Bank, the fishery scientists at the Boothbay Harbor laboratory compare existing conditions of these herring populations to determine the effect of this new fishery.

The laboratory is now a member of the U. S. research group of the International Commission for Northwest Atlantic Fisheries, and participated in the Commission's annual meeting in Halifax, Nova Scotia this month.

Scientists from Boothbay Harbor met with scientists from Canada and Russia to discuss herring research in the offshore waters of the Gulf of Maine, and cooperative research efforts are planned for the coming years.

One of the most critical problems to be answered through this cooperative venture is the relationship of the offshore adult herring populations to the inshore sardine populations. Proper management of the sardine fishery is dependent on a knowledge of the entire life history of this species.

### AGEING TECHNIQUE

Other recent advances in the research at Boothbay Harbor include a method of ageing sardine-sized herring. This has been a difficult task as the fish scales, which are generally used to determine age, do not show a consistent annual pattern.

Other hard-parts of the sardine were examined and age determinations are now possible with earbones (otoliths). Rings of growth on the earbones can be interpreted to assign the year of birth and present age of each sardine examined — knowing the ages, the fishery biologists can compute the percentage contribution of sardines of different ages to the fishery; and from this can study the success of each year class.

This ageing technique has confirmed the information deduced from the size of sardines in previous years — that the fish contributing to the fishery consist of three age groups, one-two- and three.

Generally, each season is dominated by two-year-old sardines, and in 1962 over 90 per cent of all the fish packed were in this group. In some years, when the abundance of two-year-old fish is low, the one-and three-year-old fish are canned in greater numbers.

In past years, the sampling of the fishery to obtain the needed biological data has been severely limited. This year, sampling will be conducted on a coastwide basis and will provide comparative data from the eastern, central and western portions of the coast of Maine.

The initiation of this sampling program is possible only through the cooperation of the State of collect the samples, and through the cannery operators who have offered facilities for this collection.

### GOOD COOPERATION

As in so many fishery research efforts, the cooperation of fishermen and industry personnel is essential to the success of the program. This cooperation in the Maine Sardine Fishery has been outstanding and is strong evidence of the progressive interest in fishery research.

This cooperation has many facets. Fishermen have been particularly helpful in the tagging studies which are designed to trace the migrations of sardines. Under the expanded research program, these studies will be intensified to provide information about the behavior of sardines and about the natural death rates of this species.

Obtaining the live fish for this work has been simplified through the cooperation and knowledge of the fishermen. The success experienced in recovering tagged fish depends on the cannery employes and the managers who collect the tags and provide the pertinent were captured.

With the new research efforts, information about the herring and the sardine fishery will be increased substantially and contribute markedly towards the continued success of one of Maine's leading industries.

Portland Press Herald, June 29, 1963

**U. S. Fisheries Biological Lab At Boothbay Harbor**

Extensive tests will be conducted at the Boothbay Harbor biological laboratory of the U. S. Bureau of Commercial Fisheries to find answers to some of the questions baffling the sardine industry on herring shortages. Federal funds received last fall make this study of the biology of herring possible. The new research vessel, Albatross IV will conduct extensive cruises in the Gulf of Maine.

INFLUENCE OF FRESHWATER ENVIRONMENT ON SURVIVAL OF COHO SALMON. William A. Smoker, Auke Bay Biological Laboratory, Auke Bay, Alaska.

Adult coho salmon, Oncorhynchus kisutch, are caught in their final year of life in certain fisheries in the Northeast Pacific Ocean along the North American Continent. The abundance of salmon in the annual catches is found to fluctuate at times in a similar manner as the amount of water discharged during the juvenile residence of the salmon in their natal freshwater streams. The procedure for measuring salmon abundance and combined stream discharges is described, and the possible reasons for the close correlations are discussed.

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From Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No 6, Vol. 3, P. 1381-1393. 1963.

Experience Paper No. 22

# STUDIES OF THE ERYTHROCYTE ANTIGENS OF ALBACORE, BIGEYE, SKIPJACK, AND YELLOWFIN TUNAS AND THEIR USE IN SUBPOPULATION IDENTIFICATION

By

LUCIAN M. SPRAGUE, JAMES R. HOLLOWAY
and
LESLIE I. NAKASHIMA
U.S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

## Abstract

Initial studies of the serology of albacore, bigeye, skipjack, and yellowfin tunas are discussed. The discovery in bigeye of a blood group system containing two blood factors, A and B, which form four phenotypes A, B, AB, and O is noted, and gene frequency estimates are calculated consonant with the hypothesis that the system is determined by the inheritance pattern of three allelic genes. The importance of being able to study such systems for subpopulation analysis is pointed out.

The relationships of several other blood factors within the four tunas studied were discussed and the K set of blood factors in the B system of skipjack was analyzed. This system provided evidence for reproductive isolation between at least two and probably three subpopulations in the area of four island groups: Hawaii, the Marquesas, the Tuamotu, and the Society Islands.

# ETUDE DES ANTIGENES ERYTHROCYTES DU THON GERMON, DU THON OBESE, DE LA BONITE A VENTRE RAYE ET DU THON A NAGEOIRES JAUNES

## Résumé

L'article présente des recherches initiales portant sur la sérologie du thon germon, du thon obèse, de la bonite à ventre rayé et du thon à nageoires jaunes. Il signale la découverte chez le thon obèse d'un système de groupes sanguins contenant deux facteurs sanguins, A et B, qui forment quatre phénotypes A, B, AB et O, et les estimations de fréquence des gènes se montrent en accord avec l'hypothèse selon laquelle le système est déterminé par la distribution héréditaire des trois gènes alléliques. Les auteurs soulignent l'importance que l'étude de tels systèmes présenterait dans l'analyse des sous-populations.

Ils commentent les relations qui peuvent exister entre plusieurs autres facteurs sanguins dans les quatre espèces de thon étudiées et ils analysent l'ensemble K des facteurs sanguins dans le système B de la bonite à ventre rayé. Cette méthode apporte la preuve de l'existence d'une reproduction séparée de deux, au moins, et probablement trois sous-populations dans la zone des archipels des Hawaï, des Marquises, des Tuamotou et des Iles de la Société.

## ESTUDIOS DEL ERYTHROCYTE ANTIGENS DE ALBACORA, PATUDO, BARRILETE Y ATUN DE ALETA AMARILLA Y SU EMPLEO EN LA IDENTIFICACION DE SUBPOBLACIONES

Extracto

Se reseñan los estudios iniciales de la serología de albacora, patudo, barrilete y atún de aleta amarilla. Se menciona el descubrimiento en el patudo de un sistema de grupo de sangre que contiene dos factores, A y B, que forman cuatro fenotipos: A, B, AB, y O y se hacen estimaciones de la frecuencia de genes de acuerdo con la hipótesis de que el sistema lo determina la modalidad de la herencia de los tres genes alélicos. Se pone de relieve la importancia de poder estudiar tales sistemas para el análisis de subpoblaciones.

Se reseñan las relaciones de varios otros factores de la sangre dentro de los cuatro atunes estudiados y se analiza el grupo K de factores sanguíneos en el sistema B del barrilete. Este sistema facilitó las pruebas del aislamiento reproductivo entre por lo menos dos, y probablemente tres, subpoblaciones en aguas de cuatro grupos de islas: Hawaii, Marquesas, Tuamotu y Sociedad.

## 1 INTRODUCTION

The purpose of this report is to give an account of our initial studies of the antigens found on the erythrocytes of four Pacific tunas: albacore, bigeye, skipjack, and yellowfin. This study was undertaken to establish serological techniques whereby reproductively isolated stocks of tuna could be recognized by identifying genetically controlled antigens on the surface of the red blood cell envelope. Three blood group systems called B, C, and A-B-O are described, and several additional blood factors not yet identified with a particular blood group system are discussed.

The studies of numerous authors have discussed or shown the utility of this approach to the problem of distinguishing reproductively isolated populations within a single species (Cushing, 1952; Cushing and Sprague, 1952, 1953; Ridgway, 1957; Sindermann and Mairs, 1959; Suzuki, 1961; Suzuki et al., 1958, 1959, 1960; Ridgway and Klontz, 1960; Sprague and Vrooman, 1962; Marr and Sprague, in press).

## 2 MATERIALS AND METHODS

The results reported in this paper were obtained from blood samples drawn from four major species of Pacific tuna: albacore, bigeye, skipjack, and yellowfin.

Samples were collected via cardiac puncture and held in a modified Alsever's anti-coagulant containing 16 g sodium citrate, 41 g dextrose, and 14.5 g sodium chloride in 2 litres of $H_2O$. Stored in a refrigerator at approximately 7° C, the samples showed very little hemolysis over periods of 2 weeks to 2 months, depending on the species.

The reagents used in these studies were saline extracts of legume seeds and normal and immune animal sera. All reagents were kept in a freezer at -20° C in their undiluted state. Prior to testing they were thawed and diluted to proper strength.

The seed extracts were prepared by soaking 1 g of ground seeds in 5 ml of modified Alsever's at room temperature overnight. The solution was then centrifuged and the supernatant poured off. The supernatant was further diluted 1:6 for testing.

Absorbed and unabsorbed cattle and goat normal sera were prepared in a single standard dilution of 1:8. When questionable results occurred, absorptions were used as the final criteria of classification.

The immune sera were obtained from rabbits specifically immunized against bigeye, skipjack, or yellowfin tuna. These sera were also used as absorbed or unabsorbed reagents, and were diluted appropriately before testing, usually 1:16 to 1:64.

Absorptions of the normal and immune sera were performed using standardized techniques. In each instance 2 volumes of diluted sera were first absorbed by a single volume of tightly packed erythrocytes at room temperature for 10 minutes and then by a second volume of erythrocytes at 7° C for 20 minutes.

Titre for the absorbed sera ranged from 1:8 for the goat normal sera to 1:96 for rabbit immune serum.

## 3 BLOOD-TYPING TECHNIQUE

The procedures used to study each sample of tuna blood were as follows: .05 ml of reagent followed by .025 ml of a freshly washed 10-percent erythrocyte suspension were drawn into a 1.3-1.5 x 75 mm tube by capillary action. The total fluid involved occupied approximately three-quarters of the volume of the capillary tube. The tube was inverted and imbedded in soft clay contained in a slot on the face of a plastic block. The clay sealed the tube and held it in a near vertical position. This position allowed the cells to fall slowly through the reagent and maximum reaction to take place.

Agglutination readings were made by inverting the blocks and were recorded after 1 to 1-1/2 hours.

A scoring system employing the designations negative (.), trace (tr), and one (1) through four (4) was used. The weakest agglutination which could be observed macroscopically was designated a trace and the strongest clumping was designated a four. In the tables of this report only the summary designations "positive (+++)" or "negative (.)" are recorded.

## 4 NOMENCLATURE

In order to conform generally to conventional notation, serologically related sets of reactions detected by various reagents are designated as "systems" of blood groups, remembering that the present usage of this term is a special one, since the necessary genetic information, obtained from inheritance data, relating the reactions to allelic sets of genes is not available. It is assumed, however, that the erythrocyte antigens of tuna are the products of genes, as in other species. Evidence that this assumption is correct is presented below for the A-B-O system of bigeye.

## 5 SEROLOGICAL FINDINGS

### 5.1 The bigeye tuna

Two blood group systems and several additional blood factors have been demonstrated for the bigeye tuna.

#### 5.1.1 The C system

Bovine normal sera have been shown to contain natural heteroagglutinins which react with many but not all tuna erythrocytes (Cushing, 1956). The blood factor recognized by such sera, which we have designated $C_3$, was the first factor of the C system to be recognized.

Two other blood factors which form regular serological subtyping relationships with $C_3$ are now recognized. These blood factors $C_1$ and $C_2$ were revealed by absorptions of rabbit anti-bigeye immune sera with selected bigeye red blood cells (RBC).

Table I shows the results of testing 335 bigeye blood samples with anti-$C_1$, anti-$C_2$, and anti-$C_3$ reagents. The pattern of phenotypes formed by these reactions constitutes a typical regular linear subtyping relationship.

#### 5.1.2 The A-B-O system

Anti-A reagent was obtained by the absorption of rabbit anti-yellowfin immune serum R329 by selected bigeye bloods. Anti-B reagent was obtained by the absorption of bovine normal serum C347 by selected bigeye bloods. We propose that

Table I

Bigeye tuna from Hawaiian waters classified according to the four phenotypes of the C system. This table demonstrates the linear subtyping relationship of the reagents anti-$C_1$, anti-$C_2$, and anti-$C_3$

| Phenotype | Reagent | | | Individuals tested |
|---|---|---|---|---|
| | Anti-$C_1$ | Anti-$C_2$ | Anti-$C_3$ | |
| $C_1$ | +++ | +++ | +++ | 184 |
| $C_2$ | · | +++ | +++ | 34 |
| $C_3$ | · | · | +++ | 60 |
| " " | · | · | · | 57 |
| | | | | 335 |

the four phenotypic patterns detected by these reagents constitute a blood group system which is in form analogous to the human A-B-O system.

Both R329 and C347 contain various anti-C fractions. In each case it was necessary to remove these fractions before proceeding to an analysis of the anti-A and anti-B fractions of the serum; the relevant absorptions are shown in Tables II and III.

Anti-A reagents were prepared by absorptions similar to those shown in Table II. Bloods similar to 732 and 758 remove all C fractions from the serum R329 but fail to remove the anti-A components of the serum. Bloods of type O, C-negative (not shown) do not react in absorptions of either anti-C or anti-A fractions, while 630 and 749 and similar bloods completely exhaust the antibodies anti-C and anti-A from this serum.

Anti-B reagents were prepared from bovine normal serum C347 by selected bigeye bloods used in absorption experiments as shown in Table III.

Bloods similar to 704 and 694 remove all anti-C fractions but do not remove anti-B from the serum. Bloods similar to 695 do not remove

Table II

Absorption of rabbit anti-yellowfin serum R329 by selected bigeye bloods to obtain the anti-A reagent. The absorbing and test cells are individually classified according to their C system and A-B-O system phenotypes to illustrate the types of cross reactions involved.

| Tested by bigeye RBC number | Rabbit anti-yellowfin serum R329 absorbed by bigeye RBC number | | | | | C and A-B-O phenotypes of test RBC | |
|---|---|---|---|---|---|---|---|
| | 732 | 758 | 749 | 630 | Unabs. | C | A-B-O |
| 724 | +++ | +++ | . | . | +++ | "_" | A |
| 726 | . | . | . | . | +++ | $C_3$ | B |
| 749 | +++ | +++ | . | . | +++ | $C_1$ | AB |
| 760 | . | . | . | . | +++ | $C_1$ | O |
| 615 | +++ | +++ | . | . | +++ | "_" | A |
| 630 | +++ | +++ | . | . | +++ | $C_1$ | A |
| C | $C_1$ | $C_1$ | $C_1$ | $C_1$ | | C and A-B-O phenotypes of absorbing RBC | |
| A-B-O | B | O | AB | A | | | |

either anti-C or anti-B fractions. Bloods similar to 702 will remove anti-B fractions but not the anti-$C_2$ fractions. Bloods similar to 653 remove all demonstrable antibody fractions from this serum.

Table IV shows the results of cross absorption experiments with the anti-A and anti-B reagents with various A, B, AB, and O bloods. The results of these absorptions are those expected by our assumption that these anti-A and anti-B reagents regularly classify the four A-B-O phenotypes.

In 1924 Felix Bernstein proposed a theory of the heredity of the A-B-O blood groups of man which he derived from the consequences of the Hardy-Weinberg law (Wiener and Wexler, 1958).

Simplified, Bernstein's formula states that $\sqrt{\bar{O} + \bar{A}} + \sqrt{\bar{O} + \bar{B}} - \sqrt{\bar{O}} = 1$ where $\bar{O}$ is the proportion of group O individuals, $\bar{A}$ the proportion of group A individuals, and $\bar{B}$ the proportion of group B individuals observed. This relationship holds for situations in which random mating exists and tests the theory that the four phenotypes in the population--A, B, AB, and O--are the products of the segregation of three allelic genes.

We have shown in Table V data on 427 bigeye tuna collected near Hawaii. The data in Table V are presented according to the expectations of Bernstein's formula. The observed value of 0.992 for Hawaiian bigeye tuna is not significantly different from the expected value 1.000.

We conclude from this observation that the observed data conform to those expected on a hypothesis of three allelic genes segregating to produce four phenotypes in the proportions shown, or, in other words, a blood group system like that of the A-B-O groups of man. Thus it may be said that the bigeye sampled were obtained from a single subpopulation.

Table III

Absorption of bovine normal serum C347 by selected bigeye bloods to obtain the anti-B reagent. The individual absorbing and test cells are classified according to their C system and A-B-O system phenotypes to illustrate the types of cross reactions involved.

| Tested by bigeye RBC number | Bovine normal serum C347 absorbed by bigeye RBC number | | | | | | C and A-B-O phenotypes of test RBC | |
|---|---|---|---|---|---|---|---|---|
| | 704 | 694 | 702 | 653 | 695 | Unabs. | C | A-B-O |
| 724 | . | . | . | . | . | . | "−" | A |
| 725 | . | . | . | . | . | +++ | "−" | O |
| 726 | +++ | +++ | . | . | +++ | +++ | $C_3$ | B |
| 728 | . | . | +++ | . | +++ | +++ | $C_2$ | O |
| 729 | +++ | +++ | +++ | . | +++ | +++ | $C_2$ | AB |
| 695 | . | . | . | . | . | +++ | $C_3$ | O |
| C | $C_1$ | $C_1$ | $C_3$ | $C_1$ | $C_3$ | | C and A-B-O phenotypes of absorbing RBC | |
| A-B-O | O | A | B | B | O | | | |

5.1.3 Other factors

There are several additional blood factors which are recognized, in bigeye, by the agglutinating action of saline extracts of the following legume seeds: the soy bean (Glycine max), the common bean (Phaseolus vulgaris), and seeds of the trees Caragana arborescens and Virgilia divaricata. These blood factors appear to be independent and are not now recognized as part of any known blood group system.

5.2 The skipjack tuna

Two blood group systems and a variety of individual blood factors are recognized in skipjack tuna.

5.2.1 The C system

The blood factor $C_3$ detected by hetero-agglutinins found in bovine normal sera is the only blood factor in the C system of skipjack observed by us. Only two classes of individuals in the C system are recognized, $C_3$-positive and $C_3$-negative.

5.2.2 The B system

The blood factors E, $K_1$, and $K_2$ form a pattern of related reactions in skipjack which we have named the B system.

E-positive erythrocytes are recognized by the agglutinating action of saline extracts of Virgilia seeds. The two blood factors $K_1$ and $K_2$ are recognized by the agglutinating action of absorbed and unabsorbed rabbit immune serum R-60. The factors $K_1$ and $K_2$ exhibit a regular subtyping relationship, demonstrable in phenotype patterns and absorption results. Table VI gives the numbers of individuals observed in the three patterns formed by the K set of reactions in the B system. Table VII shows the results of absorbing rabbit anti-skipjack immune serum (R-60) by selected individual skipjack bloods. Cells similar to 992, 993, and 997 absorb all detectable antibodies from R-60. Bloods similar to 994, 995 and 1000 absorb a fraction of the antibodies from R-60 but fail to absorb that fraction which reacts with 992, 993, and 997. Bloods of the first group are called $K_1$. Bloods of the second group are called $K_2$. Cells

Table IV

**Absorption of the anti-A and anti-B reagents by A, B, AB, and O bigeye bloods to demonstrate typical cross reactions. Reagents pre-absorbed to remove anti-C fractions.**

| Tested with bigeye RBC number | Anti-A reagent absorbed by selected bigeye blood number | | | | | | A-B-O phenotypes of test RBC |
|---|---|---|---|---|---|---|---|
| | 820 | 821 | 825 | 834 | 830 | Unabs. | A-B-O |
| 820 | . | . | . | . | . | . | O |
| 821 | . | . | . | . | . | . | B |
| 834 | +++ | +++ | +++ | . | . | +++ | A |
| 830 | +++ | +++ | +++ | . | . | +++ | AB |
| A-B-O | O | B | B | A | AB | | A-B-O phenotypes of absorbing RBC |

| Tested with bigeye RBC number | Anti-B reagent absorbed with selected bigeye blood number | | | | | | A-B-O phenotypes of test RBC |
|---|---|---|---|---|---|---|---|
| | 820 | 821 | 825 | 834 | 830 | Unabs. | A-B-O |
| 820 | . | . | . | . | . | . | O |
| 825 | +++ | . | . | +++ | . | +++ | B |
| 834 | . | . | . | . | . | . | A |
| 830 | +++ | . | . | +++ | . | +++ | AB |
| A-B-O | O | B | B | A | AB | | A-B-O phenotypes of absorbing RBC |

Table V
The application of Bernstein's formula to data collected from 427 bigeye from Hawaiian waters

| Phenotype | Individuals observed | |
|---|---|---|
| | Number | Percent |
| A | 42 | 9.8 |
| B | 56 | 13.1 |
| O | 319 | 74.7 |
| AB | 10 | 2.3 |
| | 427 | |

Bernstein's formula states that:

$$\sqrt{\bar{A} + \bar{O}} + \sqrt{\bar{B} + \bar{O}} - \sqrt{\bar{O}} = 1$$

Therefore, given the above data we observe that:

$$\sqrt{9.8 + 74.7} + \sqrt{13.1 + 74.7} - \sqrt{74.7} = .992$$

Table VI
Classification of 1,014 skipjack by means of anti-$K_1$ and anti-$K_2$ reagents to show the pattern of relationships between $K_1$ and $K_2$ bloods

| Reagent | | Number of Individuals |
|---|---|---|
| Anti-$K_1$ | Anti-$K_2$ | |
| +++ | +++ | 523 |
| . | +++ | 268 |
| . | . | 223 |
| +++ | . | 0 |
| | | 1,014 |

Table VII
Absorption of rabbit anti-skipjack immune serum R-60 by selected cells to demonstrate the pattern of absorptions of the blood factors $K_1$ and $K_2$ in the B system.

| Tested with skipjack RBC number | Rabbit anti-skipjack serum R-60 absorbed by skipjack RBC number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 992 | 993 | 997 | 994 | 995 | 1000 | 939 | 941 | Unabs. |
| 992 | . | . | . | +++ | +++ | +++ | +++ | +++ | +++ |
| 993 | . | . | . | +++ | +++ | +++ | +++ | +++ | +++ |
| 997 | . | . | . | +++ | +++ | +++ | +++ | +++ | +++ |
| 994 | . | . | . | . | . | . | . | . | +++ |
| 995 | . | . | . | . | . | . | . | . | +++ |
| 1000 | . | . | . | . | . | . | . | . | +++ |
| 939 | . | . | . | . | . | . | . | . | . |
| 941 | . | . | . | . | . | . | . | . | . |

similar to 939 and 941 do not agglutinate in either $K_1$ or $K_2$ reagents. Absorption results with these cells are similar to those with bloods 994, 995, and 1000 in that all $K_2$ fractions are removed.

Table VIII lists the number of individuals observed in the six patterns formed by the E reaction and the K set of reactions. The E and K relationships will be commented on in the discussion.

5.2.3 Other blood factors

The saline extracts of legume seeds described in the section on bigeye also detect blood factors in the skipjack. None of these factors appear to be important to subpopulation research except the blood factor E (mentioned above) detected by Virgilia divaricata extracts.

5.3 The albacore tuna

Albacore bloods (807) from a variety of localities--Japan, New Caledonia, North America (west coast), Samoa, and South Africa (south coast)--have been examined. In the C system both blood factors $C_2$ and $C_3$ have been recognized, while the blood factor $C_1$ has not yet occurred in samples tested.

Several additional blood factors are also recognized both by immune reagents and by the extracts of legume seeds. These blood factors have not yet been assigned to a particular blood group system. It is probable that the A-B-O system described for bigeye also occurs in albacore, as anti-A and anti-B reagents cross-react with albacore erythrocytes. However, these sera also contain additional cross-reactive antibodies which must be removed before albacore bloods may be rigorously classified in an A-B-O relationship.

The $G_1$-$G_2$ set of relationships, detected by tilapia immune sera (Sprague and Nakashima, 1961), has not been studied further as the volume of reagent obtainable from tilapia was so small as to be uneconomical.

Table VIII
Classification of 1014 skipjack individuals with respect to the six patterns formed by their reaction to reagents E, $K_1$, and $K_2$ of the B system

| Reagent | | | Number of individuals |
|---|---|---|---|
| "Anti"-E | Anti-$K_1$ | Anti-$K_2$ | |
| +++ | +++ | +++ | 13 |
| +++ | . | +++ | 125 |
| +++ | . | . | 203 |
| . | +++ | +++ | 510 |
| . | . | +++ | 143 |
| . | . | . | 20 |
| | | | 1014 |

Extracts of legume seeds also detect albacore blood factors, but as yet they have not provided useful data for subpopulation studies.

### 5.4 The yellowfin tuna

Blood factors $C_1$, $C_2$, and $C_3$ in the C system, as well as individual blood factors Y, H, A-like, and B-like are detected in yellowfin by reagents obtained from animal sera.

The legume extracts used with bigeye also detect individual blood factors in the yellowfin. The legume Lathyrus sp., supplied by Mr. Klawe of the Inter-American Tropical Tuna Commission, shows promise as an effective reagent for yellowfin subpopulation studies.

## 6 SKIPJACK POPULATION STUDIES

Some preliminary studies of tunas collected from a variety of geographic localities have been made, however, the number of samples tested or, in some cases, the reagents available for testing have been too few for us to report in detail studies of tuna other than the skipjack.

Skipjack samples were collected and tested with reagents E, $K_1$, $K_2$, A, D, and $C_3$ in the vicinity of Hawaii (21° N, 158°W), the Marquesas (9° S, 140°W), the Tuamotu (16° S, 146° W), and the Society Is. (16° S, 151° W).

Of the reagents used, only those of the B system have been useful in characterizing populations from different geographic areas. Of the B system reagents, only the K set of reagents was reliable enough to draw reasonably accurate inferences relative to genetic rather than serological variables. Table IX shows the frequency of occurrence of the K phenotypes in the B system in each of the areas sampled. Table X shows the same data arranged in such a way that the 99-percent confidence limits of the observed frequency may be compared.

There were several significantly different proportions of K-phenotypes found (Table X). For example the samples from the Marquesas Is. and the Hawaiian Is. are significantly different at the 1-percent level in respect to the frequencies of both phenotypes, $K_1$ and "__".

Summarizing the data shown in Tables IX and X, we interpret these data as providing evidence for the occurrence of at least three reproductively isolated populations of skipjack in the areas sampled. In our opinion, at least three reproductively isolated populations have been sampled, but we cannot exclude on the basis of the present data the unlikely possibility that some mixture of two populations has occurred in such a way as to yield the proportions observed. The most likely situation is that each of three areas--Hawaiian Is., Marquesas Is., and Society-Tuamotu Is.--is represented by a characteristic biological subpopulation, or subpopulations. There is the possibility that for any single area there are seasonally or biologically distinct populations which occur in the area that are not represented by our samples. (See Marr and Sprague, in press, for a discussion of hypothetical situations of this sort.)

## 7 DISCUSSION

### 7.1 Serological studies

A variety of blood factors first recognized in one species are found in additional species as they are tested. The relationships between the blood factors often fall into some sort of familiar serological pattern such as regular subtyping

Table IX

**The relative numbers of individual skipjack in samples from four geographic areas, classified according to the three phenotypes obtained by testing with anti-K reagents of the B system.**

| Sampling area | Total number | Phenotype | | | | | |
|---|---|---|---|---|---|---|---|
| | | $K_1$ | | $K_2$ | | $\overline{K_1}\ \overline{K_2}$ | |
| | | Number observed | Proportion in percent | Number observed | Proportion in percent | Number observed | Proportion in percent |
| Hawaiian Is. | 234 | 154 | 66 | 74 | 32 | 6 | 3 |
| Marquesas Is. | 250 | 83 | 33 | 67 | 27 | 100 | 40 |
| Tuamotu Is. | 360 | 193 | 54 | 81 | 23 | 86 | 24 |
| Society Is. | 170 | 93 | 55 | 46 | 27 | 31 | 18 |

Table X

**The observed K phenotype proportions of skipjack (see Table IX) listed by area of capture tabulated with the 99-percent confidence limits of the observed proportion (compare vertical columns, or phenotypes by area).**

| Sampling area | Phenotype | | | | | |
|---|---|---|---|---|---|---|
| | $K_1$ | | $K_2$ | | $\overline{K_1}\ \overline{K_2}$ | |
| | Observed proportion | 99% confidence limits of observed proportion | Observed proportion | 99% confidence limits of observed proportion | Observed proportion | 99% confidence limits of observed proportion |
| Hawaiian Is. | 66 | 58 to 74 | 32 | 24 to 39 | 3 | 0 to 5 |
| Marquesas Is. | 33 | 26 to 38 | 27 | 20 to 34 | 40 | 32 to 48 |
| Tuamotu Is. | 54 | 47 to 60 | 23 | 17 to 28 | 24 | 18 to 30 |
| Society Is. | 55 | 45 to 65 | 27 | 19 to 36 | 18 | 11 to 26 |

relations, A-B-O, or MN, etc. Some examples of this sort follow in the discussion of the C system and A-B-O system of bigeye. Sometimes, however, no known pattern exists to explain the observations; the relationship of the blood factor E to $K_1$ will provide an example of such a case, and is worth documenting if for no other reason than to caution the unwary.

### 7.1.1 The C system

The C system blood factors $C_1$, $C_2$, and $C_3$ occur in both bigeye and yellowfin tuna. The blood factors $C_2$ and $C_3$ occur in albacore, but $C_1$ has not yet been found. The blood factor $C_3$ is the only member of this system found in skipjack. Because blood factors of the C system have been found in all tuna studied and because there is considerable variation as to the particular blood factor represented in a given species, this blood group system may eventually provide some useful information on the taxonomic relationships of the tunas.

### 7.1.2 The A-B-O system

The A-B-O system of bigeye is of particular interest to us because it is the first example in our laboratory of a blood group system which conforms to the expectations of the Hardy-Weinberg Law. The importance of the ability to carry out an analysis by means of the Hardy-Weinberg Law has been discussed elsewhere (Marr and Sprague, in press).

Blood group systems having the general form of the classical A-B-O groups of man have been reported for several species of fishes.

Studies of the freshwater brown bullhead (Ictalurus nebulosus) have shown an A-B-O system detected by the presence of isoagglutinins (Cushing, 1952). The Tg system of albacore (Suzuki, et al., 1958, 1959) also forms such a pattern (Marr and Sprague, in press). The S system of the spiny dogfish (Squalus acanthias) has been shown to be of the A-B-O pattern (Sindermann and Mairs, 1961). These authors present genetic evidence of the inheritance of the blood factors of the S system by means of a comparison of the blood types of female dogfish and their unborn progeny. Such studies are of great value to us because they formally demonstrate the applicability of well known genetic principles, chiefly derived from studies of man and of domestic and laboratory animals, to the study of pelagic fishes.

The two reagents, anti-A and anti-B, which delineate the A-B-O system of bigeye bloods also contain antibody fractions which cross-react with albacore and yellowfin, and as these species are studied further they may prove to be amenable to Hardy-Weinberg analysis.

Skipjack bloods do not cross-react with any of the antibody fractions contained in anti-A or anti-B sera.

### 7.1.3 The B system

The blood factors of the B system, $K_1$ and $K_2$, are recognized only in the skipjack. The blood factor E recognized in skipjack by Virgilia extracts falls within the B system. The blood factor E seldom occurs in bloods that are $K_1$-positive (Table VIII).

A variety of absorption experiments performed by us to clarify this relationship have shown that more than one reactive fraction is present in the saline extracts of Virgilia divaricata seeds which produce the E reagent. However, these experiments rather than clarifying the relationship between $K_1$ and E have only served to deepen our perplexity concerning the nature of the fluids producing E reactions.

### 7.1.4 Other blood factors

The miscellaneous immune reagents which recognize the blood factors Y and H have only recently been developed, and will not be discussed, nor will we discuss a variety of other blood factors detected by legume seed extracts.

## 7.2 Population studies

Our initial comparisons between skipjack captured in different geographic localities utilized the E reagent (Sprague and Nakashima, MS.). In that study we observed in the sample from the Tuamotu Is. a very low frequency (.038) of occurrence of E-positive skipjack. In the data reported here (Table IX) we were unable to repeat this observation. Several potential reasons for this occur to us, such as sampling error, errors in experimental

technique, or the existence of a real but ephemeral population of skipjack. However, we do not have any rational method of choosing among these alternatives, and we must at present regard this observation as an enigma.

The general development of reagents which define blood group systems amenable to Hardy-Weinberg analysis will minimize the difficulties of interpreting the results of utilizing such troublesome fluids as the E reagent and will also make it possible to give a critical account of whether or not there is "mixing" and what the nature of various potential mixtures of individuals from different populations might be.

## 8 SUMMARY

Initial studies of the serology of albacore, bigeye, skipjack, and yellowfin tunas are discussed. The discovery in bigeye of a blood group system containing two blood factors, A and B, which form four phenotypes A, B, AB, and O is noted, and gene frequency estimates are calculated consonant with the hypothesis that the system is determined by the inheritance pattern of three allelic genes. The importance of being able to study such systems for subpopulation analysis is pointed out.

The relationships of several other blood factors within the four tunas studied were discussed and the K set of blood factors in the B system of skipjack was analyzed. This system provided evidence for reproductive isolation between at least two and probably three subpopulations in the area of four island groups: Hawaii, the Marquesas, the Tuamotu, and the Society Is.

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# SHARKS *and* SURVIVAL

## *Chapter 3* Field Observations on Large Sharks of the Florida-Caribbean Region

By Stewart Springer

# *Chapter 3* Field Observations on Large Sharks of the Florida-Caribbean Region

By Stewart Springer[1]

## THE FLORIDA FISHERY FOR LARGE SHARKS

The fishery for large sharks, centered at Salerno on the west coast of lorida, remained in continuous and prosperous operation from 1935 until it as liquidated in 1950. It was discontinued only because a less expensive ›urce than shark livers was found for the vitamin A needed for fortifying ıimal feedstuffs.

Although fishing operations were carried out continuously only in the imıediate vicinity of Salerno, fishing was extended after 1945 from the Carolinas › the Amazon, on either a seasonal or an experimental basis. The sharks were aught chiefly by longlines set on the bottom. Floating longlines and gill nets ere also used occasionally, and various other methods of fishing were tried xperimentally.

A wide range in monetary values of Florida sharks, with variance in species, ze, sex, and condition, made it necessary for the principal company in this shery to keep comprehensive records of catches in order to make equitable ayments to the fishermen. Usually each shark was measured and recorded. ı complicated but satisfactory system of bonus payments to workers for yproducts such as hides, fins, and meat made accurate length measurements ecessary. Because it was found that the most valuable livers were worth as ıuch as a hundred times the value of others of similar size and because valable livers required special handling and processing for realization of their ull value, the shark station records were amplified to cover several factors ffecting liver value.

The Florida shark fishery was forced by the economic situation to give pecial attention to the preliminary assay of liver oil before processing and to elective fishing in order to get a high proportion of products with relatively

[1] U.S. Fish and Wildlife Service.

high values. During the later period of operation of the fishery at Salerno, it was not unusual to run 50 or more quantitative determinations of vitamin A daily, not only on lots of various sizes but also on single livers. Such assays formed the information base for selective fishing.

From 4 to 10 species of large sharks were included in the normal catch from one day of fishing by a Florida shark-fishing vessel. It was found by trial and error that sharks with greater than average liver-oil potencies could be obtained by selecting specific areas, seasons, and depths, as well as specific kinds of gear for fishing effort. Although guidelines for selective fishing were developed entirely on an empirical basis, it became apparent that the criteria for selective fishing were those that would bring in 1) more of those species having a comparatively high vitamin A potency, 2) more sharks in the older age groups, and 3) more sharks that had lived for a substantial portion of their lives in an area characterized by a high rate of vitamin A accumulation.

It is not known whether sharks require unusually large amounts of vitamin A or whether this oil-soluble vitamin merely accumulates in the liver without being subject to any substantial withdrawal for ordinary physiological processes. At birth, the young sharks have a large proportion of oil in their livers (more than 50% in most large species of Florida sharks) but little or no vitamin A. The total amount of vitamin A in the liver appears to increase from the time of birth, at a rate characteristic of the species, for as long as the shark lives. The rate of accumulation, however, appears also to be subject to such conditions as the kind and amount of food ingested and various unknown environmental factors. The potency of the oil (the amount of vitamin A per unit weight of oil) tends to have an inverse relation to the proportion of oil in the liver. Fasting, courtship, and the nourishment of developing young seemingly require the withdrawal of substantial amounts of oil from the liver without greatly affecting the total amount of vitamin A.

If we classify shallow-water marine environments of the world according to the potency of liver oil characteristic of sharks living in those areas, the western North Atlantic would have to be considered a low-potency area. For example, the common spiny dogfish in the western North Atlantic has low-potency liver oil, whereas this species in the eastern North Pacific has liver oil of moderately high potency.

In the western North Atlantic, however, sharks of large size and great geographical range show substantial differences in vitamin A potency when compared according to various subareas. As a general rule, the highest potencies are found in sharks on the continental coasts of the southern Caribbean; the next highest are found in sharks off the middle Atlantic states; and extremely low potencies are found in sharks in the West Indies and the Gulf of Mexico. An interesting and unexplained phenomenon is that the Gulf of Mexico, insofar as its continental shelf areas are concerned, appears to provide little material that permits sharks to accumulate vitamin A. Sharks that have obviously lived there for most of their lives have liver oil that is, perhaps,

t: lowest in vitamin A to be found in sharks from any part of the world. Sarks that have obviously come into the Gulf from other areas carry much ore of the vitamin.

To develop policies for the control of fishing and processing, the fishery erators made tentative deductions, based on fishery records, concerning the tribution and habits of sharks. The data were quite satisfactory for this rpose, but no effort was made to assemble the facts so that they would be eful for scientific demonstration of biological principles. Sharks were not gged, nor was any method developed to determine definitely their ages or as of origin. Nevertheless, some facts about movements and habits were tablished beyond a reasonable doubt.

Almost anywhere along the coasts of Florida, some large sharks could caught at any time within a few miles of the shoreline. This situation pre- red a kind of economic trap for shark fishermen because catches of small mbers of large sharks could be made from practically any set of a shark e that had a hundred or more properly baited hooks. Such daily landings a few sharks were falsely encouraging and led fishermen to persist in mar- nal production. The company carrying out the principal operations in the hery found it unprofitable to deal with fishermen whose operations were arginal. Thus it was very important to the company as well as to the fisher- en to know the whereabouts of denser concentrations of sharks.

## PRINCIPAL AND ACCESSORY POPULATIONS

Although general patterns in migration, distribution, and life history can be awn from data on Florida shark-fishing operations and landings, exceptions pear too frequently not to make some attempt to explain them.

*For the purposes of this discussion, I have divided into two parts the total pulation of each migratory species of large shark in the temperate and sub- pical western North Atlantic region. For convenience, I shall call one part e "principal population" and define it as the main breeding population — e core of the total population of a species within the selected regional limits - or as the part of the total population that maintains its numbers and fol- ws regular patterns of distribution and habit. The other part of the total pulation, the "accessory population," is that which is lost, and usually per- anently lost, either through wandering from the usual geographical range of e species or through disorientation in seasonal movements, which puts it t of phase in the reproductive cycle.* The numbers in the accessory population ctuate but are maintained at a low level by recruitment from the main popu- tion. Although reproduction may occur at rare intervals in the accessory pulation, little, if any, increase is contributed to the total population, because t-of-range and out-of-phase young seem to stand little chance of survival.

The extent to which such a general statement about populations of larg sharks would apply should be expected to vary from species to species an from area to area. The concept is useful to account for the distribution of vary ing vitamin A potencies among Florida sharks and also has some applicatio in the consideration of sharks as a hazard to man.

It is possible that sharks of the accessory populations are represented i attacks on man disproportionately to their numbers. This does not mean tha sharks of principal populations are harmless to man; certainly some of the are predictably dangerous. Farther on in this chapter, evidence from the di tribution of sharks in the Florida area and from the feeding habits of Florid sharks is brought forward in support of the thesis that there is a dual proble in understanding the shark hazard: one part deals with principal populatio and the other with accessory populations.

In southern Florida the fisherman's term for the sharks producing margin catches was "bank loafers." If tiger sharks, *Galeocerdo cuvieri,* are exclude all of these bank loafers would probably fit my earlier definition of membe of accessory populations. During my association with the shark fishery as company man, one of my principal duties was to discourage fishermen fro fishing for bank loafers. This required fishing in somewhat deeper water an more attention to such details as use of fresh bait and well sharpened, brig hooks. In many areas, fishing on concentrations of sharks was possible f only brief periods, because seasonal movements of the main aggregations le only a scattering of bank loafers and tiger sharks.

It was found by expensively gained experience that reports of sighting of sharks, of damage to fishing gear other than shark fishing gear, and captures of sharks in harbor mouths were all unreliable as indications areas of concentrations of large sharks. Conversely, the best shark fishing wa found usually in areas where sharks were not locally known to be numerou More members of accessory than of principal populations come into conta with man by wandering into shallow water or harbors and by remaining co spicuous as residents of areas frequented by boats. Reports of the presen of sharks from sources other than shark fishermen usually indicated that onl sharks of accessory populations were present.

From the point of view of the shark fisherman, sharks of the accessory popu lations have three noteworthy characteristics: they are scattered everywher they are easy to catch even with spoiled bait, and there are never enough them in one area to bring shark fishing up to the economic break-even poin Occasionally, in otherwise slack seasons, a fisherman would make fairly goo catches of these sharks by moving his gear 20 to 30 miles along the coa every day and by spreading his hooks over a greater length of groundline.

Much that can be said about accessory populations of shark species necessarily vague and may be expected to remain so. We know that th Florida sharks we have herein assigned to accessory populations are general

solitary, separated from main concentrations of their species in time or space, and show little evidence of food preferences common to sharks of the principal populations. Such sharks appear to be lost or disoriented. Many of them seem to be either young sharks or very old ones, and it follows that accessory populations are characterized by a much greater range in vitamin A potency than are sharks from principal populations. Females are usually nongravid, and the number of sharks of the accessory populations showing major injury or deformity is much greater than in the principal populations.

Because large sharks of accessory populations come more often to shallow coastal waters than do those of principal populations, they may be relatively more important in problems of shark attacks on man than are members of principal populations. Recognition of these sharks as belonging to a special category has been given by Coppleson (1958 and 1962) with the term "rogue" shark and by Florida shark fishermen with the designation "bank loafer."

Tiger sharks in the Florida area are distributed in such a way that an accessory population cannot be recognized. The white sharks of the inshore waters of the Florida region fit the criteria set up here to define accessory populations. Unfortunately, however, we do not know anything about a principal population of white sharks. Practically nothing is known about white sharks that is based on an adequate series of observations or specimens. If all the available data on white sharks in all parts of the world were assembled, the result would probably be insufficient to show a well-defined pattern of distribution or regularity of habit. Also, it is possible that most of the observations were made on white sharks that were not behaving typically and that were outside the normal range of the species.

In the Florida shark fishery, over a period of 10 years, only 27 white sharks in 100,000 large sharks of all species were recorded. Those taken were caught inside the 20-fathom curve and most of them in less than 10 fathoms. They were from 6 feet to 18 feet 6 inches long; the large ones, at least, were caught on improperly set longlines so loose that the sharks became involved with more than one hook and usually had a twist of chain or wire rope knotted around the caudal peduncle.

The power of a large white shark is difficult to estimate. In the fishery these sharks were able to break wire rope or chain having a breaking strength of approximately 3,800 pounds. Since many white sharks weigh as much as 3,800 pounds, this does not seem unreasonable. Dynamometer tests made while shark fishing showed initial pulls, without a run, of as much as 1,500 pounds for a 10-foot hammerhead. An adult silky shark — a species weighing not more than 350 pounds — could, if permitted a 20-yard run, always break a new 12-thread manila rope but could not break a new 21-thread manila rope when the rope was snubbed. The minimum breaking strength of 12-thread manila rope is approximately 1,350 pounds; that of 21-thread, 2,650 pounds. The silky shark is one of the more vigorous swimmers among the carcharhinids,

but there seems no reason to ascribe to it any extraordinary quality of swim ming power not possessed by the white shark. The foregoing explains wh most of the larger white sharks taken by the shark fishery were caught b fishermen with little experience. Broken lines and straightened hooks wer common occurrences in shark fishing, but certainly not all could have bee the result of white-shark activity.

Most of the white sharks were between 14 and 16 feet long, and most wer females, all nongravid. This suggests that all of the white sharks taken in th Florida fishery were members of an accessory population. Makos were take in about the same numbers as white sharks, but the makos were caught depths from 5 to 130 fathoms, and there was no evidence that makos were to strong to be caught on the gear in use. No gravid females were caught, and large proportion of those taken bore marks of severe injury or were judged t be in bad physiological condition because of their small livers. Makos are rela tively common in midwater depths of 20 fathoms or more beyond the edge o the continental shelves near Florida, and catches of gravid females in offshor waters of the Gulf of Mexico and the Caribbean are frequent. Thus there is somewhat better basis for regarding the makos of Florida shallow waters as a accessory group.

Sharks of the accessory populations appear to be disproportionately danger ous to man, not only because they are more likely to be in inshore waters bu also because their feeding habits are appreciably different from habits norma to the species. The reputation sharks have for being unpredictable in behavio may be derived from reports of experiences with members of the accessor shark populations. On the other hand, the Florida commercial shark fisherme found the sharks of principal populations among the most predictable o marine creatures.

An interesting article by Kurt Severin (1953), which was published in popular magazine, gives an account of the sharks of Lake Nicaragua. Severi suggests, on the basis of some real evidence, that the population of *Carcha rhinus nicaraguensis*[2] is actually recruited from sharks entering the lake by wa of the San Juan River. Severin's investigation lends considerable support t the thesis that the bull shark of Lake Nicaragua is a member of an accessor population of *Carcharhinus leucas*. Its differences in feeding habits fro *C. leucas* are of the sort expected from members of an accessory populatio The lake shark is easily caught, indiscriminate in feeding, and exceptionall voracious and bold.

Additional detail about the lake sharks, especially to answer questio about the frequency of the birth of young in the lake, should show definitel whether that form should be regarded as an accessory population of *C. leuca* Additional data would be most valuable for a resolution of several relate

[2] While this article was in preparation, *C. nicaraguensis* was placed in the synonymy o *C. leucas* by Bigelow and Schroeder (*Copeia*, 1961, no. 3, p. 359).

oblems if a comparative study could be made of the bull sharks in Lake bel, Guatemala; the sharks of Lake Nicaragua; the flourishing population at t mouth of the San Juan River in the Caribbean; and the Pacific sharks merly called "chottos" by commercial shark fishermen operating from a se at Punta Arenas on the Pacific coast of Costa Rica. Mr. Robert Dorion, resident of Guatemala, has (in correspondence) called my attention to rious complexities in the classification and distribution of sharks on opposite es of Central America. He has provided data and has also sent a large ecimen of the Lake Isabel bull shark to the United States National Museum.

## SYSTEMATICS OF LARGE SHARKS

A total of 27 species of large sharks — that is, those regularly reaching ngths of more than 5 feet — were taken by shark fishing vessels operating t of Salerno, Florida. Of the 13 species that were taken commonly, 11 were some extent seasonal in occurrence. No great difficulties were encountered making identifications of the rare or unusual sharks landed at Salerno, but e common sharks of the genera *Carcharhinus* and *Sphyrna* were not sorted t satisfactorily until several additional names were provided for the fishermen d the dock workers. Nomenclature was not important to the fishermen, but was necessary to distinguish the valuable sharks from those of lesser value.

Local names would have sufficed had not the shark fishery expanded its erations over most of the Atlantic coastal waters from Cape Hatteras to e Amazon and had it not looked toward further expansion into tropical acific waters. The principal shark-fishing company in Florida found that stable nomenclature and the use of universally acceptable scientific names ould have greatly enlarged the information base needed to develop plans r extending operations. For example, it would have been helpful for the shing company to know something about the relationships of the two or more mmon and valuable species called the "chotto" by fishermen both in the aribbean and on the Pacific coast of Central America. It would have helped so if the company could have relied on the validity of names given by suppliers of small lots of high-potency oil from distant areas.

The present status of classification of the larger common species is quite nsatisfactory because it has developed largely on a regional basis. Studies ading to satisfactory nomenclature on a worldwide basis are certainly as important to an understanding of shark behavior as they were to the commercial nark fishery.

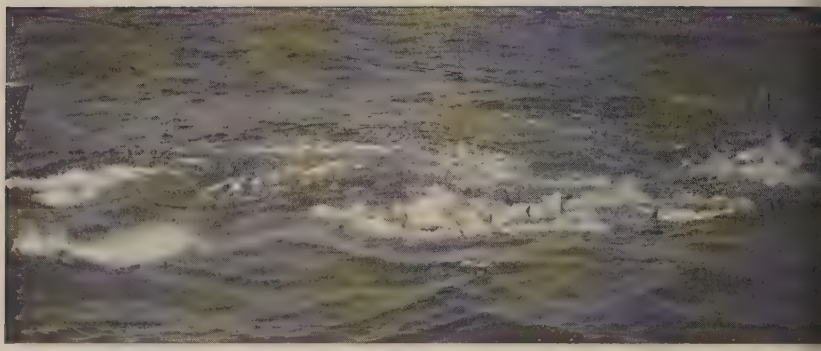

Fig. 1 Spinner sharks feeding on trash fish thrown overboard from shrimp trawler off Jacksonvill Florida.

Fig. 2 Shark fishing vessel preparing to land catch at Salerno, Florida.

## DISTRIBUTION OF LARGE SHARKS

**gration** The records of the shark fishery furnish much useful informa-
n on the migratory movements of a few species of large sharks of the
stern North Atlantic. But these data also indicate great variation among
cies in migratory movements, as well as complex distribution patterns.

The large sharks can cover great distances; certainly the adults of some
cies make annual migrations of many hundreds of miles. The most exten-
e, as well as the most regular, movements in the region are accomplished
adults of those populations having nursery ranges exclusively in the more
therly latitudes. For example, this observation applies to the principal
stern North Atlantic populations of the sand shark, *Carcharias taurus,* and
sandbar shark, *Carcharhinus milberti.* Seasonal temperature change is un-
ubtedly important in the stimulation of migratory movements of sharks, but,
ce some species may merely go deeper to reach water of a suitable tempera-
e, migration routes may need description in three dimensions. For adults of
ne species, it is obvious that migratory patterns are established as a result
drives stimulating the females to go to specific areas to give birth to their
ung. It is possible that there are drives leading the adults of both sexes to
ecific mating areas, but evidence of this is scanty.

Certainly for some species, and perhaps for many, the migratory patterns
e confused by the fact that the geographical ranges of the adult males, the
ult females, and the young overlap but do not totally coincide. The very
ct that, in any given locality along the southeastern coast of the United
ates, a single species may be represented seasonally by one sex or by either
ults or young exclusively makes it difficult to collect data on life histories.
y own observations on patterns of distribution among these sharks lead me
believe that there are about as many distribution patterns as there are
ecies. Furthermore, a pattern of distribution in one region is not necessarily
plicable to the same species in another region. The bull shark, *Carcharhinus*
*ucas,* population in the Gulf of Mexico is migratory, whereas that in the
cinity of Trinidad appears to be nonmigratory.

Actually, although there is enough information to show where and when
arks are present in Florida waters, knowledge of where they migrate —
rth, south, or offshore — is generally lacking. The movement patterns of
ly the sandbar shark have been pieced together from various sources, and,
en so, the result is not entirely satisfactory (Springer, 1960).

Two species of the large shallow-water sharks of southern Florida — the
rse shark, *Ginglymostoma cirratum,* and the tiger sharks — exhibit
inimum migratory habits. Some portions of the populations of nurse and
ger sharks inhabiting the Florida Keys area in winter seem to move north-
ard in summer. Nurse sharks appeared at Salerno in summer in sufficient
mbers to make gill-net fishing for them profitable for a few weeks, but at the
me time they remained abundant in the Florida Keys area.

The tiger shark is exceptional in many ways. From the records of th fishery, I find no evidence of schooling, no disparity in numbers of males an females, and no indication of absence of any size group within the populatio although the numbers of tiger sharks, especially large ones, were found to in crease somewhat in winter in the Dry Tortugas area. Tiger sharks have bee observed frequently to be associated in groups of 2 to 6 or more, but suc associations may be transitory or merely groups assembling because of th presence of food. The tiger shark is abundant in the shore waters of th northern part of the Gulf of Mexico in the warm months but absent in winte The records from that area do not show segregation by size or sex, howeve and evidently the species has no specific nursery area. Tiger sharks were n sought for vitamin A, and principal and accessory populations were not d fined or recognized. I know of no other species with such a homogeneous di tribution in the shore waters of southern Florida nor of any other botto dwelling species so little restricted by bottom type. Like the sharks of th accessory populations of other species, tiger sharks were easily caught by fis ermen and rather quickly eliminated as an important part of the catch.

**Some physical factors affecting distribution** Despite the obvious impo tance of water temperature in stimulating migrations of large sharks, it seem probable that many tropical species can tolerate much cooler water than th apparently choose when migrating. It is surprisingly difficult to use determin tions of water temperature as a guide in selecting a good spot for commerci fishing, probably because other environmental conditions are involved. Fishi observations indicate that sharks can stand sudden changes in temperatu much better than most of the bony fishes. Near Salerno, a period of col water upswelling in June annually stunned or killed great quantities of fi and, for a few days, provided the best shark fishing of the year. It was not many times when catches of the same species were being taken over a wi depth range, and consequently over a wide temperature range, that sharks fro deep, cool water were much less active than their counterparts from shallow and warmer water. This damper on activity, however, seems to affect shar less than some of the bony fishes, and therefore it may be to the shark's co petitive advantage.

Warm water apparently provides more rigid limits for sharks than do cold water. I can find no specific records, however, of the upper limits temperature tolerance by sharks. My own observations as a shark fisherm in the Florida Key area suggest that all large sharks, except possibly t nurse shark, leave the shallows during hot, still weather. In hot weather, they appear at all, it is to move inshore through the deeper channels, and th only at night on a rising tide or during periods of rough water. The sha fishermen in this area believed that shark fishing in water warmer than 85° was useless.

The lower oxygen-carrying capacity of warm water, coupled with the ten

y of sharks toward increased activity in warm water, may be the critical or for some species, rather than any direct effect of temperature.

recall the capture of a dusky shark, *Carcharhinus obscurus,* about 10 feet g, on the anchor portion of a shark line where there were no hooks. The rk had merely bitten down on the chain and had died there. Similar observaions were moderately frequent, and death presumably resulted from suffocain whenever large sharks of certain species were prevented from continuing ward motion that would force water over the gills. But despite the apparent idence that the dusky shark died from suffocation, it is not certain that inadeate gill aeration was the only factor involved. When the shark stopped its ward motion, the ordinary swimming movements stopped and likewise the portant aid given to the blood circulation by these movements. We might go ther and speculate that the entire respiratory reflex mechanism of large rks is weak and inadequate and does not provide sufficient auxiliary stimuto mark a dangerously reduced oxygen supply.

Light intensity may act as a repellent to some species and may also influence rks in their unwillingness to approach some tropical shores. Tiger sharks primarily nocturnal, and those species with large green eyes — the nightrk, *Hypoprion signatus,* the bigeye thresher, *Alopias superciliosus,* and the vsharks, *Hexanchus* — are not known to approach within several hundred t of the surface, even at night. The species with small eyes — notably the non shark and the bull shark — are active in very shallow water day and ht.

The Florida fishermen believed that currents also had an important effect the distribution and movements of sharks. Large aggregations of sharks med to move with the currents, but, since the effect of bait juices in the ter is directed down-current, there appears to be some advantage to sets eddies. On the east coast of Florida, unfortunately, movements of the axis the Gulf Stream associated with changes in wind direction confuse the uation. To set a longline of chain or wire rope on the bottom requires careful ention to currents for proper results. Longlines were anchored and buoyed both ends and usually were picked up on the morning following an afternon set. The velocity and direction of the currents frequently change during night. One effect of current change was an increase in the catch, but anher was difficulty in retrieving the lines. When changes were violent, sinking the buoys and occasional loss of lines cost the fisherman many hundreds dollars. The most successful fishermen on the east coast of Florida seemed be those who could stay close to current margins or faces between weak, uthbound, inshore currents and the northbound Gulf Stream without loss gear.

**me biological factors affecting distribution** The loss of a shark longline s a serious event, not only because it represented an immediate expense for w equipment and a delay but also because of the possibility of "burning out"

the grounds. Lines lost because of current and weather changes usually we loaded with sharks. If they were not picked within 3 or 4 days, the surroun ing area for perhaps 5 miles in any direction was regarded as worthless f shark fishing for several weeks. New shark fishermen found it hard to belie that the decomposition of 30 or 40 large sharks in an area ruined it as a fishi spot, but one or two experiences convinced them.

Since some sharks eat other sharks, even when these are in less than a fre state, and since the presence of a line of decomposing sharks apparently do not immediately drive sharks away from an area but does prevent them fro taking fine fresh bait, it seems to me that the action of the decomposing sha flesh comes from something more subtle and perhaps more powerful than simple repellent material.

While I was a member of the crew of a shark fishing vessel, we went out our way some 200 miles to check a Caribbean Bank as a fishing spot. We s one line on the bank and caught one tiger shark and a few newborn silk sharks. As soon as we had recovered our line, the skipper headed us bac toward our original destination. This meant a loss of about 4 days of fishi time, and I broke a strict rule of that skipper and asked him why we did n make a thorough check over all the 60-mile-long bank. He told me that it w plain that we were in a nursery area, that the mothers of the young sharks w had taken would not bite even if they were still in the area, and that all w would catch would be a few scattered tiger sharks.

It is evident that sharks do not take baits readily in the vicinity of lar quantities of decomposing shark flesh, but whether they are actually repell or merely stop feeding and wander to other areas is not clear. Fishing resul also show that postgravid female sharks do not feed in the nursery groun of their own species and therefore do not eat their own young, and that ma sharks do not feed during courtship.

The explanation offered, speculatively, is that the sharks are influenced their behavior by their gustatory senses. Stimuli are received through senso crypts (Budker, 1938) in the skin of the head and body. These stimuli, pe haps related qualitatively to the stimuli received in higher vertebrates throu common chemical receptors, may result from specific complex chemicals th are present in the water in extremely small concentration. If we accept th general explanation as a sufficient reason for scientific and experimental stud we are faced with a difficult problem. We know very little about our ow chemical sense, and here we are postulating on reasonable evidence, fro morphology and behavior, that the chemical sense of sharks is more high developed than our own. It would certainly not be unreasonable to expe that, over the millions of years of evolutionary separation of sharks and oth vertebrates, the primitive chemical sense has, in sharks, become specializ and relatively more important. Since we have practically no experience with comparable sense of our own, we may find experimental study — which und the most favorable conditions requires both rigorous logic and an imaginati approach — extremely difficult.

## FEEDING HABITS OF LARGE SHARKS

Shark fishermen had two sources of information on the food preferences of sharks: the examination of shark stomachs and estimates based on comparative success with various baits. Florida shark fishermen, oriented to the capture of sharks of the accessory populations and tiger sharks, found that shark stomachs contained almost everything, and also that sharks would bite on almost any kind of bait — fish, fowl, or mammal — either fresh or partly decomposed. Fishermen oriented to fishing for sharks of principal populations found that sharks ate fresh fish, that fresh fish were successful bait, and that the stomachs of the species of sharks they sought usually contained fish.

Sharks of the accessory populations usually had livers with substantially higher vitamin A potencies than sharks of the principal populations. This encouraged a number of persons to engage in shark fishing after preliminary investigation and sampling of the product's value. The samples usually included only the more easily caught sharks — those of the accessory populations. Assays of liver oil from such samples suggested a higher potency for most species than would be found with production at a high level. In spite of the relatively higher value of their livers, sharks of the accessory populations were not numerous enough to support a continuing fishing operation, even by one vessel.

Giving the evidence from the economic side the greater weight, but also considering evidence from fishing records, the principal fishing company developed some standard operating procedures for fishing and for baiting and setting shark lines. These vary somewhat according to area and kinds of sharks sought. These methods were successful, and consistent deviation from them always resulted in economic failure of the fishing operation. It seems reasonable to assume that the methods had some valid basis from which deductions about feeding habits may be drawn.

The fishing company strongly recommended that all longlines be set out in line with the tide or current and not across it, and that all lines contain at least 10 hooks, each baited with not less than 1 pound nor more than 2 pounds of cut bait. Experience had shown that it was important to develop a concentrated chum streak, or line of diffusing bait juices, that would lead groups of sharks as well as single sharks to the line.

A scarcely less important recommendation was that hooks be sharpened and brushed bright and smooth every day. The points of the hooks were never hidden, and bait was put on in such a way that the hook was not choked. In areas of good fishing, 1 out of about 20 sharks caught with bright, sharp hooks was snagged by a hook through a fin or through some part of the body away from the mouth. In addition, it was suspected from the frequency of sharks taken in clusters that the turmoil generated by a fin-hooked shark aroused interest in the area on the part of any other shark in the neighborhood. It was reasoned that big catches were likely when sharks were attracted to the set early and when the line became a center of turmoil.

The largest single longline fishing cost, aside from labor, was the cost o bait. One shark-fishing boat set a minimum of 200 hooks each night and con sequently required an average of 300 pounds of bait daily. Experience prove that the best bait for all sharks was freshly cut fish, and that bait frozen whe fresh was next best. Of the species of fish available in southern Florida waters the little tuna, *Euthynnus alletteratus,* or the Atlantic bonito, *Sarda sarda* appeared to be the best bait. No doubt, other small tunas would have bee equally successful had they been available. Whole fish of any kind seeme to make poor bait, so it was necessary to select fish weighing 2 pounds o more. Except for the small tunas, the only available first-quality fish for bai appeared to be the crevalle jack, *Caranx hippos,* and the great barracuda *Sphyraena barracuda.* Many species were not tried, of course, because of thei small size. Other species such as the dolphin, Spanish mackerel, and amberjac were used occasionally in small quantities by fishermen who caught them whil trolling to and from shark longlines. Notably unsuccessful as bait wer snappers, groupers, and mullet.

One independent shark-fishing crew operating entirely in the Gulf o Mexico used porpoise meat for bait almost exclusively and with considerabl success. The operation specialized, however, in catching tiger sharks and bul sharks. It changed fishing areas frequently, sweeping the coast from Tortuga to mid-Louisiana, and stopped fishing entirely during slack seasons.

Another fishing crew working on the coast of the Guianas was quite suc cessful in catching bull sharks. These were especially desirable from that re gion, but not from the Gulf of Mexico. This crew used fresh shark bait alter nately with bait cut from frozen little tuna. Generally, the bull sharks appeare to be attracted by the tuna but bit on the hooks baited with shark meat. Line baited exclusively with pieces of shark flesh were unsuccessful.

Too few white sharks, mako sharks, thresher sharks, or whitetips wer taken by the Florida shark fishermen to provide much background for estimat of normal diet. By combining information from apparent bait preference stomach examinations, and observation, estimates of feeding habits of som of the common Florida sharks have been formed and are given in the follow ing pages.

**Tiger Sharks** The tiger shark is completely omnivorous. It swallows indi vidual large conchs, such as *Fulgur* or even the giant horse conch, whole, an those of moderate 6- to 8-inch length by the dozen. In some undetermine way the shells are removed in the shark's digestive tract. Perhaps the shell are dissolved by the hydrochloric acid of the shark's stomach. I have see tiger-shark stomachs full of conchs complete with shells and others full c conchs with neither whole calcareous shells nor any remnant of shell, but have not found partly dissolved conch shells in tiger-shark stomachs, possibl because the chemical activity, once started, may temporarily divert the shar from interest in a baited shark hook. Conch opercula are not digested but ten

ccumulate in the posterior tip of the tiger shark's stomach past the pylorus. ch opercula are more commonly present than not in tiger-shark stomachs n the Florida Key area.

have also found large tiger-shark stomachs full of horseshoe crabs, *nulus,* as well as pieces of large sea turtles, porpoise heads or pieces of poise, sea birds, and pieces of large fish. Garbage and artifacts are comnly present. Apparently, anything small enough to be swallowed by the rk may be eaten. I once found, in a tiger shark, an unopened can of salmon e salmon was judged in excellent condition by organoleptic test); at other es I found a good leather wallet with no money in it, a 2-pound coil of per wire, various articles of clothing, assorted nuts and bolts, and other cles in the stomachs of various tiger sharks. They seem to eat small fish y rarely, and, although they are probably the most frequent attackers of er sharks caught on shark lines, little evidence was found from the examiion of stomachs to indicate that tiger sharks are often successful in capturunhampered and free-swimming small sharks.

Tiger sharks apparently do not feed regularly on the spiny lobster, *Panulirus,* , occasionally, large numbers of tiger sharks taken in the Tortugas area e stomachs full of spiny lobsters.

Tiger sharks are not often seen in daylight, but they readily attack surface ts at night. Young tiger sharks are more often seen near the surface and e the impression of being less timid in light than the large ones. Aerial servations of daylight chumming tests once revealed a group of tiger sharks the bottom in about 40 feet of water beneath a pack of blacktips, *Carcharinus limbatus.* But the tiger sharks could not be induced to approach the face, and verification of the identification was made only by lowering a ted hook to the bottom and hauling in a sample.

Two tiger sharks containing portions of men were taken by shark fishermen 1942–43, one from the west coast and the other from the east coast of rida. It was impossible to determine whether the men were casualties be- e the sharks got to them.

**ll Sharks** Bull sharks may reach a weight of more than 500 pounds. mach examinations show that they occasionally eat a wide variety of rine creatures. The chief diet appears to be somewhat specialized, with a dilection toward small sharks. This is the only species showing a preferce for shark as bait. Bull sharks were also taken regularly with porpoise ces as bait.

Bull sharks are common in shallow water in the northern part of the Gulf Mexico in summer, and they regularly enter estuarine waters to give birth their young. Before I really accepted the possibility that bull sharks could dangerous, I encountered some while I was wading in waist-deep water at t Island in Mississippi Sound, and I found them so docile that I was able to e a couple of them a shove. Now that I have had more experience with the

power of these sharks, I realize that I was lucky not to get my ribs cracked c at least a severe abrasion from the meeting. Actually, these bull sharks wer probably females that had entered the shallows to give birth to their youn and were, at that time, inhibited from feeding. In view of the abundance c bull sharks on summer days near beaches of the northern Gulf of Mexico, is remarkable that this is not an area of frequent attack on bathers. I attribut the lack of attacks, by the bull shark at least, to the feeding inhibition of fe males in nursery areas. It might also be of general significance that no larg sharks in this area are permanent residents of inshore waters, and that suc members of accessory populations as appear in the region stay in relativel deep water.

In southern Florida waters a few bull sharks belong to the "bank loafer category.

**Spinner Sharks, Blacktip Sharks, and Lemon Sharks** These 3 species ma well be treated together, because in southern Florida waters all 3 are migrator and appear to feed primarily on fish and crustaceans.

An early-spring northward migration of spinners past Salerno, Florid called forth substantial but unsuccessful efforts to catch these sharks i quantity. In this migration the sharks make spinning leaps regularly. By fo lowing them with a boat it could be seen that the leaps sometimes starte below a school of very small fish, through which the sharks passed with the mouths open while following a course toward the surface. I am confident th the relatively small numbers of spinners that I have seen from distances less than 30 yards were *Carcharhinus maculipinnis,* but spinning sharks we also rather commonly observed at greater distances and at a considerab distance from shore. I have no way of knowing whether all spinners observe were *C. maculipinnis.*

Spinners were taken in large numbers from inshore waters of the nortl eastern coast of Florida and along the coast of Louisiana in the early sprir and through the beginning of summer. Young are born at this time, but th adults remain in the shallow waters for 2 to 4 months, where they feed on fi along beaches and follow shrimp vessels to pick up trash fish thrown ove board. It is possible that the spinners then move southward and spread o over deep water, at which time they are generally not caught with the kinds fishing gear used.

These sharks seem to have somewhat more specialized feeding habits th blacktips. The spinner sharks, *Carcharhinus maculipinnis,* have appreciab smaller teeth than the blacktip, *C. limbatus,* although spinner sharks are large Blacktip habits are apparently somewhat similar to spinner-shark habi except that blacktips remain in inshore waters along the coasts of the Unit States for longer periods and seem to use the spinning technique for feedi less often or not at all.

emon sharks, *Negaprion brevirostris,* which are considerably heavier than ter the spinner or the blacktip, were much more important to the shark ery. Lemon sharks taken north of Jacksonville, Florida, or along the hern coast of the Gulf of Mexico appeared to be members of the accessory ulation. The principal population is West Indian, but its nursery range in- es peninsular Florida, chiefly the Florida Bay–Florida Key area. nach examinations indicate that lemon sharks are primarily fisheaters. reover, a definite preference for fish is shown by results from fishing with ous kinds of bait. Off-season catches of a few lemon sharks with abnormally vitamin A liver potency suggest the existence of a small accessory popula- in southern Florida. The lemon shark is also suspected of moving south- d and occasionally offshore in winter, and a few observations but no cap- s in offshore waters beyond the edge of the continental shelf suggest that species may use some special feeding techniques during its offshore rsions.

**mmerheads** All of the 3 large species of hammerheads in the western th Atlantic were taken off the Carolina coast. In this area, *S. zygaena* was n frequently. *S. zygaena,* however, was represented only by relatively few -grown examples in catches at Salerno. No specimens of *S. zygaena* were n south of Salerno. The species is said to be present in cooler waters of western Atlantic in both the Northern and Southern Hemispheres, but, e no specimens other than those in the Salerno catches were taken by the k fishery south of the Carolinas, it seems doubtful that various old records n the Gulf of Mexico, the West Indies, and the Caribbean are based on ect identifications.

n early summer run of hammerheads off Salerno was found to consist pri- ily of adult male, *S. lewini,* and adult female, *S. mokarran,* and included w half-grown *S. zygaena.* Large hammerheads were the most valuable cies available to the Florida shark fishery because they had the highest ncy liver oil of any common species. Stomach examinations indicated that mmerheads less than 10 feet long eat small fish and crustaceans primarily, that those more than 10 feet long, chiefly *S. mokarran,* eat a greater ety of food, including stingrays and small sharks.

Observations indicated that hammerheads were the first species to reach ly baited shark lines; haulbacks, while setting, produced more hammer- ds than other species. After being hooked, the hammerheads died quickly were among those sharks most likely to be eaten by other sharks. In the instances when free-swimming sharks could be observed from the surface, mmerheads seemed to be avoided by other species. Great hammerheads, *nokarran,* over 12 feet in length were all females, and possibly most of n would fit our definition as members of an accessory population.

**Ridge-Back Sharks,** *Carcharhinus* The Florida shark-fishing operation w supported primarily by captures of 6 species of ridge-back sharks of the gen *Carcharhinus*. More than half of the sharks caught were sandbar sharks, a the bulk of the liver oil in the higher-potency range was obtained from dus sharks. Of the ridge-back group, only the dusky shark could be taken appreciable numbers on bait other than fresh or frozen fish. Stomach examin tions indicated that the usual diet of all 6 species is fish. But the larger dus sharks, weighing more than 400 pounds, frequently were found to have turt remains, pieces of porpoise, or shark in their stomachs.

Dusky sharks of the principal population on the east coast of Florida a found most abundantly in large schools in depths of 30 to 150 fathoms. Sh low-water dusky sharks in this area appear to be an accessory populatio since they are solitary and very sparsely distributed. Both dusky sharks a the silky shark, *Carcharhinus falciformis,* are found in greatest abundan along the edges of the continental shelf, but, of the two, only dusky sharks a found in the inshore accessory populations.

**Nurse Sharks and Sand Sharks** Limited numbers of nurse sharks, whi were useful to the local shark station for their hides, were taken with anchor gill nets in a small summer fishery near Salerno, Florida. The nurse shar frequent the shallow, rough-bottom areas in this vicinity, probably for matin and successful fishing was carried out in depths of from 10 to 40 feet. Inc dental to captures of nurse sharks, substantial numbers of sand shark *Carcharias taurus,* were taken. All of these were adults from 7 to 10 feet lon Most of them were females and were of little value for their hides because the high incidence of courtship scars. Neither the nurse sharks nor the sa sharks produce oil of sufficient vitamin potency to make these species valuab However, records of this fishing, supplemented by records of occasional ca tures of both species in experimental gill net sets in deeper water and on lon lines, did provide some general information on sand-shark distribution a feeding habits.

Adult female sand sharks are apparently common in the shallow water ne the shore. A few scattered captures from bottom-set lines between Cape Ha teras and the mouth of the Mississippi River in shallow coastal waters ind cate a more widespread distribution of adults. Thus, since longline captures the vicinity of Salerno were no more frequent than in other areas, we m conclude that adult sand sharks are not likely to be caught with baited hook Fish of various species constituted the only stomach contents found in sa sharks, and full stomachs were noted more frequently in sand sharks than any other species. Furthermore, sand sharks represent the only species fou with stomachs containing quantities of inshore game fish, such as channel ba or redfish, speckled trout, Spanish mackerel, and bluefish. Sand-shark stomac occasionally contained large sharksuckers, *Echeneis naucrates.* This is eviden that the penchant of that species for following sand sharks is a dangerous on

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# SHARKS *and* SURVIVAL

## *Chapter 18* Anti-Shark Measures

By Stewart Springer and Perry W. Gilbert

# *Chapter 18* **Anti-Shark Measures**

By Stewart Springer[1] and Perry W. Gilbert[2]

**Why should countermeasures be considered?** Man's interest in dominating his environment brings him into contact with sharks at four major impact points:

1. Sharks attack and maim or kill men under certain conditions.
2. Sharks inflict severe economic loss upon commercial fisheries, particularly in damage to fishing gear and to catches made by the gear. Sharks destroy fishing gear or spoil recreational fishing activities in some areas under some conditions.
3. Through psychological effects on man, sharks probably curtail man's recreational use of the sea in some areas and indirectly bring about economic loss to tourist service industries.
4. Sharks compete with man in the harvest of some of the more desirable food resources of the sea, and, because selectivity in man's fishing effort may inconsistently favor sharks, the net effect may be to increase the numbers of sharks or to maintain them at a relatively higher level than would be found were man's harvesting activities removed.

Accuracy of detail has been sacrificed to speak of sharks in general. Some kinds of sharks do not attack man under any conceivable conditions; many sharks are entirely harmless to commercial and sport-fishing gear; many kinds are not fear-inspiring to swimmers; and the question of the place and strength of the shark in the balance of nature is an extremely complex one that at present can be approached only on a theoretical basis, with very little empirical confirmation that a problem really exists.

The order of presentation of the reasons for shark countermeasures is not intended to reflect opinion on the relative importance of the various ways that sharks affect man. For all we know now, the long-range effect of sharks on the availability of good food resources may have much more important deleterious effects for mankind than the loss of a few men to sharks by direct attack. But we are very sure that a problem of direct attack by sharks on men exists, and we know something about its magnitude. Through studies supported by the Office of Naval Research, we now have some statistical basis for definition of the problem, and through consideration of the various facts brought

[1] U. S. Fish and Wildlife Service, Stanford University, Palo Alto, California.
[2] Cornell University, Ithaca, New York.

out in studies fostered by the Shark Research Panel of the American Institute of Biological Sciences, we have some idea of the direction research should take to reduce loss produced by shark attacks on men. Attempts to apply to the reduction of the shark hazard knowledge gained by research becomes naturally a first order of action.

It is not our intention to equate loss of human life with economic loss, but we should consider economic loss as an aspect of the general shark problem. Here it is quite certain that losses to commercial fishermen are severe, but we have only sketchy estimates of their magnitude or of their geographical distribution and frequency. From opinions and local estimates given by various well-informed people in the United States fishing industry, it appears that losses in commercial fishing gear, together with losses in fish caught in the gear but not landed, exceeds 3 million dollars annually at the fisherman's price level. The value of time lost on the fishing ground by having gear damaged and the loss in total productivity of fishing units due to their being driven from normally productive grounds by the abundance of sharks are not included in this estimate.

The most severe losses from sharks in United States fishing operations appear to occur in tuna purse seining, in shrimp trawling in certain areas, and in trawling for bottom fishes off both the northeastern and northwestern states. Damage to purse seines and to shrimp trawls is due chiefly to large sharks of several species, and damage in the northern operations in bottom trawling is due chiefly to the common spiny dogfish, *Squalus acanthias*. We do not have at hand estimates of shark damage to fisheries outside the United States. Damage by sharks to catches of tuna made by Japanese longline fishermen is probably substantial. In certain fisheries in some areas, as in the otter trawl fishery of the North Sea, some of the sharks taken are salable at satisfactory prices and provide some offset to economic loss from sharks to fisheries as a whole. Also, a few fishing activities directed specifically at sharks contribute to the credit side of the shark ledger. Sharks are generally in disfavor among those fishing for recreation and for sport, but we have no basis for an estimate of the importance of sharks in this situation.

Recreational use of the sea is occasionally reduced, either because of well-grounded fear of sharks or because of caution arising from doubts about the real nature and extent of the shark hazard. Indirectly this may have serious economic consequences to business near beach resorts. Again, we cannot estimate the extent of business loss. The consequences of one well-publicized attack on a bather can result in substantial economic loss to a community. Although it is probable that most people would regard a statement on the rarity of attacks in the statistical sense as correct and reasonable, it appears that people in general are less willing to accept a risk involving sharks than greater risks of almost any other kind. Rightly or wrongly, many business people feel that public attention to shark-attack incidents should be kept at a

inimum. In the past this view may have prevailed at times with very little ublic interest in sharks as an immediate danger. Now, however, press wire rvices almost insure publication of news accounts of shark attacks, at least yond the area of local business influence.

The entire catch of sharks, rays, and chimeras made by commercial fisheries the world in 1960 was about 900 million pounds.[3] This is only a little more an 1% of the total world fishery catch, excluding whales. The total fishery ndings of the world increased about 33% from 1955 to 1960, to a total of 7.73 million metric tons. To a large degree, this increase was due to the velopment of new fisheries or the great intensification of fishing effort for rtain species in limited areas. For example, more than a third of the increase n be accounted for by the phenomenal growth of the Peruvian fishery for nchovies to be converted into fish meal. Because of the scattered fishing fort for sharks, it is probable that available statistical summaries are less liable for sharks than for other fisheries. Nevertheless, it is apparent that the te of increase in utilization of sharks relative to other fishery resources is w. The trend in total world fisheries production is strongly upward and ward the selection of certain species for fishing effort.

Is it possible that fishing pressure on species most desirable to man gives e sharks an increasing share of food available from the sea? Actually, it is t difficult to see how some fisheries might help build up shark populations. he shrimp fishery of the Gulf of Mexico discards more than a billion pounds f trash fish and shrimp heads annually on the fishing grounds. Some of this, ut an unknown amount, goes to feed sharks. At times it is obvious that sharks et all the trash discarded from a shrimp haul. More often, no sharks are isible at the surface, but presumably some sharks would be expected to benefit om the trash after it reached the bottom. At the same time the shrimp fishery atches negligible numbers of sharks and has no obvious bad effect on them. s this source of food significant in increasing the numbers of sharks?

The otter-trawler for bottom fish operating within the range of the spiny ogfish off the New England coast has no market for dogfish and consequently shes intentionally for other kinds of fish, such as cod and haddock. Further- nore, he not only tries to catch other fish but also avoids catching dogfish hen possible, because the dogfish are difficult to handle, damage his nets, and nake him lose time. By not catching dogfish, does the fisherman so upset the alance in the struggle for existence that fishing maintains populations of dog- sh at a higher level than would be found in the region if there were no com- nercial fishing at all? We do not know.

Examples such as have been given could be multiplied but would lead only o a series of questions. What and how important is the role of the world's hark population in the reduction of stocks of more valuable fish and shellfish?

Figures concerning the world fisheries catch are from *Yearbook of Fishery Statistics*, 960. Food and Agriculture Organization of the United Nations.

Does predation of blue sharks on salmon, for example, seriously reduce the stocks of salmon available to man? Does the feeding activity of the hordes of dogfish reduce the amount of food available to haddock sufficiently to limit the growth of haddock populations? Does our fishing pressure for selected species threaten to change the composition of the total species mass of the oceans soon or in the foreseeable future?

We do not have the answers for these questions. If, through research, we are able to find answers, it seems quite probable that they will not be simple ones. Without answers to some of these questions, however, we cannot be sure either that we have a problem of competition for food with sharks or that if a problem exists it is in any way manageable.

**What kinds of countermeasures can be taken?** The kind of protective device useful to the lone man who for one reason or another faces a dangerous shark is limited in several ways. It must be light in weight and easily carried. It must be operable under water and function either all the time or when activated by the user. It must be safe for the user to carry and use under adverse conditions. It should be relatively inexpensive if it is to be widely used. And, finally, it must be reasonably effective in driving a shark away or in thwarting an attack. A 45-caliber automatic pistol is not satisfactory because it is not reasonably effective in driving a shark away and does not really meet any of these requirements.

Some qualifying statement should be made at the outset about protective devices. Some devices may be effective under special conditions or against certain kinds of sharks but still not be satisfactory for general use.

Explosives or special guns, for example, would, if widely used, be almost certain to kill or injure more men than sharks, although it is possible to carefully rig an explosive device so that a man in the water can use it to kill or repel sharks attacking singly in repeated trials, with reasonable consistency and with a fair margin of safety for himself.

If released by a man in the water, poisons or irritants of sufficient strength to promise protection against sharks are extremely dangerous to the man. Up to the present time no selective poison or irritant with strong specific and selective action against sharks has been found. Devices for injecting poisons into sharks have some of the disadvantages for general use already mentioned in connection with explosive devices.

One feature of the shark hazard needs special emphasis. Not all kinds of sharks respond to deterrent actions in the same way or in the same degree. Furthermore, there appear to be important individual differences among sharks of the same species. It is not possible at this time to predict with any certainty the types of response certain actions will receive from sharks. Electrical devices may eventually be so developed that they can produce predictable repelling stimuli to sharks, but, until now, attempts to deter sharks with such devices

ve been inconclusive or unsuccessful. Nothing beyond advice given in con-
ction with the report *Shark Attacks in 1959* [4] can be offered at this time as
countermeasure for the individual.

Our knowledge of effective methods for protecting commercial fisherman's
ar against shark attack is slight. Repellent dye material is expensive and
obably would have to be used in great volume to be practical for protecting
ge nets. Furthermore, it is questionable whether it would be effective under
conditions even then. The commotion of setting and hauling nets, the
tivity of fish within the net or gilled in the meshes, and the probability that
e massed fish produce substances attractive to sharks' olfactory sense are all
werful stimuli.

In theory it should be possible to arrange a series of electrodes in the net to
otect it and the catch by setting up repellent electrical fields. Not the least
fficulty in such an arrangement would be the necessity to adjust the input to
fect sharks without adverse results on the catch. Adequate tests of this kind
protection have not been made.

Fishermen are able to mitigate the danger to gear from sharks in various
ays, none entirely effective. Trawler fishermen working among large sharks
d that the cod end of the net is especially vulnerable to sharks on turns or
hen the net stops moving while they are hauling aboard and take such steps
they can to keep the gear moving at a steady rate. Longline fishermen try
avoid attracting sharks by drifting or by discharge of refuse near the starting
int for the set.

Shrimp trawlermen sometimes use a protective sleeve of poultry-fence wire
canvas over the cod end to reduce shark damage, a device reported to be
rtially effective.

Protecting swimmers and bathers at public beaches has been given special
tention in some regions of the world. A complete fence is used to protect a
thing area at Fort Amador, Panama Canal Zone. This fence is effective, but
is installed across the entrance to a cove. The installation in this instance was
ss of an engineering undertaking than would be found for most public
aches. It can be seen (Fig. 1a and b) that this shark fence is heavy and
obably is an expensive device. Shark attacks have occurred in the immediate
cinity of the cove, and signs are erected to warn waders and bathers
Fig. 2). To reduce the psychological impact without retracting the warning,
second sign with a humorous slant has also been installed in the same area
ee Fig. 3).

Not all devices intended for beach protection are effective. In July 1960,
o shark attacks occurred within 10 days of each other at Sea Girt and Ocean
ty, New Jersey. These attacks received wide publicity in the press, and

[4] Gilbert, P. W., L. P. Schultz, and S. Springer. 1960. *Science*, **132**:323–326. "Advice to
athers and Swimmers," adapted from this, is given in Chapter 21.

A

Fig. 1 Shark fence erected at Fort Amador, Canal Zone, to protect a bathing beach.

B

g. 2 Sign erected to warn waders and bathers.

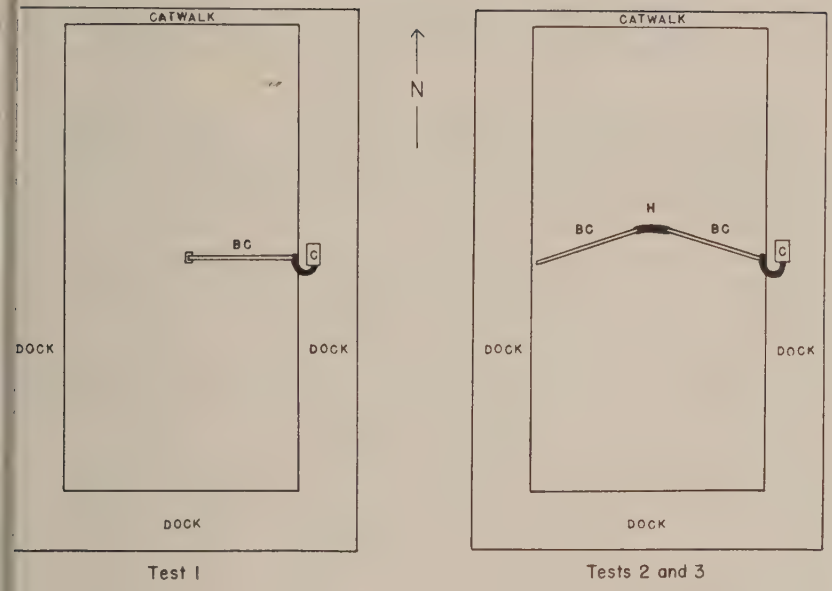
g. 3 Sign with humorous slant installed in same area.

there was understandably considerable pressure on the part of public officials to find a means to "shark-proof" New Jersey bathing beaches. According to numerous press reports, the magic answer was a curtain of bubbles rising from a garden hose punctured with a series of holes and attached to a portable air compressor. One report (*Perth Daily News,* West Australia, October 28, 1960) in the files of the AIBS Shark Research Panel states "the sharks are so terrified by the 'shark fence' that they will not cross it even to get a juicy steak, according to inventor Frank Arpin." Reports which appeared in the *Sidney Daily Telegraph* (Australia, August 28, 1960), the *Montreal Star* (Canada, August 27, 1960), the *Natal Daily News* (Durban, South Africa, August 27, 1960), the *New York Herald Tribune* (August 27, 1960), the *Evening Standard* (London, September 15, 1960), and *Life* Magazine (September 12, 1960) presented equally optimistic statements concerning the effectiveness of the bubble curtain as a barrier to large and dangerous sharks. In the November 1960 issue of *Fishing Gazette* (vol. **77,** No. 11, p. 21), the apparatus used at Sea Girt is described, and the effectiveness of the bubble barrier against sharks is summarized, as follows: "In tests of the prototype in an aquarium tank at Asbury Park, 60 large sharks [length not given] refused to crash past the barrier to reach food on the other side during a continuous five hour test." In view of the wide publicity the bubble curtain received as a positive barrier to sharks, public interest in and enthusiasm for such a method of shark-proofing beaches was not long in coming. At Sea Girt, New Jersey, a perforated hose 350 feet long was placed on the ocean floor between two jetties, 200 feet offshore from a popular bathing beach, and, according to a local hotel manager, the bubble fence proved to be "absolutely impenetrable" to sharks.

In the publicity the bubble curtain received as a positive barrier to sharks no mention was made of the species of shark repelled, their approximate length, the distance of the bubble curtain from the wall of the aquarium tank in which tests took place, or the time of day or night during which the tests were conducted. Clearly, a rigorous test of this type of shark barrier was needed before considerable sums were spent by resort areas of the world on bubble curtain equipment for shark-proofing bathing beaches.

During March and April, 1961, one of us (Gilbert) had an opportunity to test the bubble curtain rigorously on several tiger sharks (*Galeocerdo cuvieri*) which ranged in length from 5½ to 13 feet and in weight from 95 to 900 lbs. The tiger shark is one of the most common dangerous sharks of the Florida-Caribbean area, frequently wanders in close to shore, and occasionally harasses bathers. The tests were conducted at the Lerner Marine Laboratory, Bimini, Bahamas,[5] during the period March 29–April 4, 1961, in the south shark pen

[5] The writers gratefully acknowledge the use of the facilities of the Lerner Marine Laboratory of the American Museum of Natural History and the assistance of Mr. Michael Lerner in expediting the procurement of materials utilized in the bubble curtain tests. This investigation was financed with funds provided by the Biology Branch, Office of Naval Research, United States Navy.




g. 4 Plan of south shark pen at the Lerner Marine Laboratory, showing location of bubble curtain (BC), connecting hose (H), and air compressor (C).

Fig. 4). These unique pens for holding and operating on large sharks were onstructed with funds provided by the Office of Naval Research and have een described by Gilbert and Kritzler in *Science,* **132:**424, August 12, 1960.

Tests showed conclusively that many tiger sharks would pass freely through ie bubble curtain. It would appear then that the bubble curtain is ineffective s a barrier to tiger sharks (Table 1). Test data reveal that the moderately gh initial response of tiger sharks to the presence of the bubble curtain (35 irned while 51 passed through) did not continue; the sharks quickly adjusted o its presence, and the majority ignored it after the first hour. It was also oted that one tiger shark approximately 9 feet in length was repeatedly irned by the bubble curtain during the 26-hour test, and in certain of the 0-minute counts this was the only shark (of the twelve in the pen) which esponded in this way. This latter observation points up the weakness of any rogram which employs only one or two individual sharks when testing a hemical or physical agent for its repellent properties.

**hark meshing** Meshing is a method for the protection of beaches that has roved successful insofar as the record shows up to the present time. The urpose of the method is exactly the same as the purpose of the shark fence Fig. 1). However, it involves merely the systematic use of anchored gill nets

**Table I**

BUBBLE CURTAIN TESTS AT THE LERNER MARINE LABORATORY ON TWELVE TIGER SHARKS (*Galeocerdo cuvieri*)
April 3–4, 1961

| Time | Northbound: through curtain | Southbound: through curtain | Through funnel | Northbound: turned at curtain | Southbound: turned at curtain |
|---|---|---|---|---|---|
| 8:35–8:45 A.M. April 3, 1961 0835–0845 | 24 | 27 | 7 | 22 | 13 |
| 9:35–9:45 A.M. April 3, 1961 0935–0945 | 39 | 45 | 2 | 5 | 5 |
| 10:35–10:45 A.M. April 3, 1961 1035–1045 | 39 | 33 | 0 | 2 | 7 |
| 11:35–11:45 A.M. April 3, 1961 1135–1145 | 39 | 38 | 1 | 8 | 7 |
| 3:00–3:10 P.M. April 3, 1961 1500–1510 | 27 | 27 | 1 | 5 | 3 |
| 4:00–4:10 P.M. April 3, 1961 1600–1610 | 31 | 34 | 2 | 4 | 9 |
| 8:20–8:30 P.M. April 3, 1961 2020–2030 | 38 | 34 | 4 | 15 | 3 |
| 12:00–12:10 A.M. April 4, 1961 2400–0010 | 39 | 34 | 6 | 10 | 3 |
| 7:20–7:30 A.M. April 4, 1961 0720–0730 | 31 | 28 | 3 | 15 | 0 |
| 10:30–10:40 A.M. April 4, 1961 1030–1040 | 44 | 48 | 2 | 5 | 0 |
| No Curtain 7:35–7:45 A.M. April 4, 1961 0735–0745 | 40 | 50 | 1 | 3 | 5 |
| No Curtain 10:45–10:55 A.M. April 4, 1961 1045–1055 | 45 | 43 | 4 | 1 | 5 |

ar a bathing beach, but not as a complete barrier for approach to the beach ea by sharks. The gill nets catch sharks as they approach the beach area or they leave it.

Authorities of Durban, South Africa, began meshing operations in 1952 th several nets, each 450 feet long, placed parallel to the beach and about 00 feet offshore. At Durban no shark attacks occurred on 'protected' beaches er meshing was started. Australian experience in protecting beaches by shing extends from 1937, excepting the period during World War II from 43 to 1946, when equipment was not available. The record for success of shing in Australia is almost as impressive, although two attacks occurred on erewether Beach, one of about a dozen 'protected' Australian Beaches, thin an eight-year period after meshing was introduced.[6]

Both in Australia and in South Africa a great variety of methods to protect aches were tried, including the use of complete wire mesh enclosures for imming areas, but none was found to be as satisfactory as meshing.

In spite of the acceptance of meshing in South Africa and Australia, it is fficult to evaluate the method for use in other areas, because it is not certain hat factors produced the favorable record. The records do not show that shing operations drove sharks away from beaches or diverted them to other eas. The meshing removed a number of large sharks from the shark popula-ons presumably resident in the beach areas during the shark season. This moval of sharks may have been sufficient to be immediately effective in aterially reducing the probability of shark attack; however, since attacks e relatively uncommon and may, in some years, not occur at all on certain uch-used but unprotected Australian and South African beaches in the nger area, it is not certain that meshing initially affected the probability for sualty in any significant way. It has been noted that catches of sharks by shing decrease from season to season when carried out over a long period time. This suggests the possibility that the incidence of shark attack may e reduced merely because the population of large and dangerous inshore welling sharks has gradually become depleted in the vicinity of "protected" aches. Commercial shark fishing carried on in the United States before 950 had the apparent effect of temporarily reducing populations of large arks in some limited areas with comparatively little fishing effort, but this as not true of all areas. Regular migration routes were fished intensively for ars without apparent effect on the numbers of sharks present.

Meshing is essentially the same kind of operation as fishing for sharks with gill net, and the objective is to catch all of the large sharks that regularly or ccasionally come near a "protected" swimming area. As in other kinds of shing, the best results come when advantage is taken of all possible local nditions and of the habits of sharks. The amount of meshing effort neces-

We are indebted to Dr. David Davies of Durban and Dr. V. M. Coppleson of Sydney or up-to-date information on shark meshing.

sary to provide protection has not been determined. It is not known whethe the mere presence of nets off beaches tends to divert sharks from the area but this is probably not the case.

An interesting table reproduced below, extracted from a report by Dr. Davi Davies,[7] shows the trend in numbers of sharks taken by meshing at Durban i consecutive years. The initial high catch followed by a series of lower catche seems to be characteristic of all fixed fishing activities for large sharks, except ing those carried out on a main shark migration route.

Annual Catches of Sharks in Set-nets off Durban Beaches

| | | | |
|---|---|---|---|
| 1952 | 552 | 1957 | 140 |
| 1953 | 184 | 1958 | 225 |
| 1954 | 195 | 1959 | 165 |
| 1955 | 158 | 1960 | 117 |
| 1956 | 142 | | |

Electrical barriers have been considered as a means of excluding shark from access to bathing beach areas. Important difficulties, not only in desig but in cost, need to be overcome to make these practical.

The role of commercial shark fishing in control of the local or genera abundance of sharks needs more attention. Active commercial shark-fishin operations might prove to be the most effective way to reduce the local popula tions of large sharks as well as to provide effective countermeasures in th control or management of more general problems involving sharks.

**What should be done to develop more effective shark countermeasures** The element missing in all the foregoing discussion of countermeasures i sufficient knowledge of the shark and its biology in the broadest sense. Fo the most rapid, the best, and the least expensive solutions to the various shar problems, it is imperative that more be known about the basic facts of th systematics, structure, functional organization, physiology, behavior, an ecology of sharks. We should seek answers having broad application as wel as solutions to narrowly defined problems. In discussing the implications o the competition between men and sharks for the desirable resources of th sea, we have barely enough information to formulate questions.

Concurrently with basic study necessary to any adequate program to cop with sharks, continuing attempts to make practical applications of old an new knowledge are needed to answer specific problems with sharks. In thi connection, research into new ways to utilize shark products would be ver important. The least expensive way in which shark populations may be reduce is through fishing pressure, and a commercial fishery obviously needs to pa its way.

[7] South African Association for Marine Biological Research, Bull. No. 2, Decembe 1961, p. 25.

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# A New Smooth Dogshark, *Mustelus higmani*, from the Equatorial Atlantic Coast of South America

Stewart Springer and Rosemary H. Lowe

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# A New Smooth Dogshark, *Mustelus higmani*, from the Equatorial Atlantic Coast of South America

Stewart Springer and Rosemary H. Lowe

**A new shark, the smallest member of the genus *Mustelus* of the family Triakidae, is described from the coast of Surinam. *Mustelus higmani* is readily distinguishable from other plain-colored *Mustelus* by the structure of its dermal denticles. Its geographical and vertical distribution, feeding habits as shown by stomach contents, and availability to fishing gear are discussed. The study sample includes 281 adults, 79 young, and 449 embryos.**

A SERIES of smooth dogsharks of the genus *Mustelus* was taken in the summer of 1957 during shrimp trawling operations by the shrimp fishing vessel Coquette while it was employed in a fishing survey by the Government of Surinam. At about the same time (1957–59) dogsharks were found frequently in trawl catches made by the fisheries research vessel Cape St. Mary while it was engaged in a survey for the Government of British Guiana. Other specimens were obtained by Violet Graham from commercial fishing vessels operating out of Georgetown, British Guiana. Subsequently another series was assembled from catches made by the exploratory fishing vessel Oregon of the United States Fish and Wildlife Service. These dogsharks were all representative of the new species which is described here.

Comprehensive notes were made on all dogsharks collected from the Coquette during the period from June through August 1957 by James B. Higman of the Fish and Wildlife Service while he was aboard as an observer at the invitation of the Government of Surinam. On the Cape St. Mary, observations of this species were made at intervals between March 1958 and March 1959 by one of us, R. H. Lowe (Mrs. Rosemary McConnell). Additional notes on the new species were made on a summer cruise of the Oregon, in 1958, by John R. Thompson.

The new species falls clearly in the genus *Mustelus*. Studies of this genus by Hubbs (1938) and by Bigelow and Schroeder (1940) have simplified the task of describing the new species. Prior to the voyages of the Coquette, Cape St. Mary, and Oregon, specimens of the new species appear not to have been taken, or if collected, not to have been deposited in a museum collection.

We take pleasure in naming this shark for James B. Higman in recognition of his initial interest in the species and his care in the preparation of excellent notes on its natural history.

### *Mustelus higmani*, *sp. nov.*

*Holotype.*—An adult male 48 cm in total length, USNM 156930, collected by James B. Higman from the fishing vessel *Coquette* at its station 155 in approximately 12 fathoms northeast of Parimaribo, Surinam.

*Description of the holotype.*—A small slender shark (Fig. 1) having the characteristics of the family Triakidae and the genus *Mustelus* as given in Bigelow and Schroeder (1948); trunk slender, its height at base of first dorsal fin about one-tenth the total length of the shark; a ridge in the skin of the back between the dorsal fins, weak and indistinct in the posterior one-fifth of the distance between the fins; caudal peduncle slender, nearly cylindrical, without keels or precaudal pits; caudal axis little elevated. Head flattened, its sides regularly tapering from the gill region nearly to the tip of the snout without abrupt narrowing at the nostrils; snout pointed, relatively long, its length in front of mouth 7.7 per cent of total length; eye oval, its horizontal diameter about 2.5 per cent of total length; spiracle small, slit-like, located close behind eye; mouth moderately arched with upper and lower labial grooves of approximately equal length.

Fins thin; first and second dorsal fins similar in shape but the second dorsal appreciably smaller, the length of its base about four-fifths the length of base of first dorsal; origin of first dorsal over midpoint

TABLE 1. DIMENSIONS OF *Mustelus higmani* AS PER CENT OF THE TOTAL LENGTH (ARRANGED FOR COMPARISON WITH TABLE GIVEN BY BIGELOW AND SCHROEDER, 1940)

| Number of Specimens | Type Only | 3 | 3 |
|---|---|---|---|
| Sex | Adult Male | Males | Females |
| Total Length(s) in Millimeters | 480 mm | 227–478 mm | 272–524 mm |
| Tip snout to eye | 8.5 | 7.7– 9.3 | 8.0– 9.3 |
| Tip snout to front of mouth | 7.7 | 7.1– 8.8 | 7.1– 9.2 |
| Tip snout to first dorsal origin | 30.0 | 29.3–31.7 | 29.4–31.5 |
| Tip snout to origin pectorals | 23.4 | 20.5–22.5 | 21.3–21.7 |
| Tip snout to origin ventrals (pelvic fins) | 45.0 | 43.0–48.2 | 43.2–49.0 |
| Eye, horizontal diameter | 2.5 | 2.3– 3.1 | 2.3– 2.6 |
| Mouth, breadth | 6.5 | 5.4– 7.0 | 5.5– 5.9 |
| Internarial space, width | 3.0 | 2.9– 4.0 | 3.1– 3.3 |
| Labial fold, upper | 1.3 | 0.8– 1.3 | 1.1– 1.5 |
| Labial fold, lower | 1.3 | 1.1– 1.4 | 1.1– 1.6 |
| Pectoral fin, outer margin | 11.7 | 11.1–12.5 | 11.5–12.5 |
| Pectoral fin, distal margin | 8.8 | 7.5– 9.8 | 8.0– 8.5 |
| Pectoral fin, inner margin | 6.3 | 5.6– 7.5 | 6.1– 7.0 |
| First dorsal fin, length of base | 10.2 | 9.7–10.9 | 9.4–10.7 |
| First dorsal to second dorsal, interspace | 23.3 | 21.1–22.2 | 21.9–22.9 |
| Second dorsal fin, length of base | 8.1 | 7.7– 9.2 | 6.9– 8.0 |
| Second dorsal fin to caudal fin, interspace | 10.8 | 9.2–10.2 | 10.1–10.4 |
| Caudal fin, upper lobe | 18.2 | 16.5–20.5 | 18.7–20.8 |
| Pectoral fin origin to pelvic fin origin | 23.8 | 21.4–23.3 | 22.4–27.7 |
| Pelvic fin origin to anal fin origin | 21.9 | 19.4–22.2 | 17.6–21.3 |
| Anal fin, length of base | 5.9 | 5.7– 6.3 | 5.3– 6.5 |
| Anal fin to caudal fin, interspace | 8.3 | 7.5– 9.1 | 7.4– 8.5 |
| Trunk at pectoral origin, breadth | 10.8 | 9.1–10.7 | 9.6–11.0 |
| Trunk at pectoral origin, height | 9.4 | 9.0–11.9 | 8.5– 9.0 |

of the free inner margin of the pectorals, its posterior tip not quite reaching a point over the origin of the pelvic fins; origin of second dorsal much closer to origin of anal fin than to posterior tip of pelvics; pectorals comparatively small but broad, only moderately concave on their distal margins.

Dermal denticles usually 4-ridged, occasionally slightly overlapping and typically with three posteriorly projecting points instead of the single point characteristic of other species of the genus. Teeth in 77/69 rows in one adult female (not counted in type), paved, with about 5 rows visible in one aspect; basal surface of each tooth with 8 to 15 short ridges not extending more than half the distance toward the cutting or grinding edge of the tooth; principal teeth with low lobe-like crowns, their inner (toward the gullet) faces with an angled edge (worn?).

Color light gray without marking, shading to white on the ventral surfaces.

Total number of vertebrae 137, body vertebrae 88, caudal vertebrae 49 (radiographs for making vertebral counts prepared by J. A. F. Garrick and V. G. Springer).

*Diagnosis.—Mustelus higmani* is by far the smallest species of the genus. It is unique in the genus in having dermal denticles with three points. In several *Mustelus* species it is not unusual to find a few scattered denticles having one or two small lateral points or irregularities but the denticles of *M. higmani* are distinctly different—having a form intermediate between the denticle shapes characteristic of *Mustelus* and some kinds of *Triakis*.

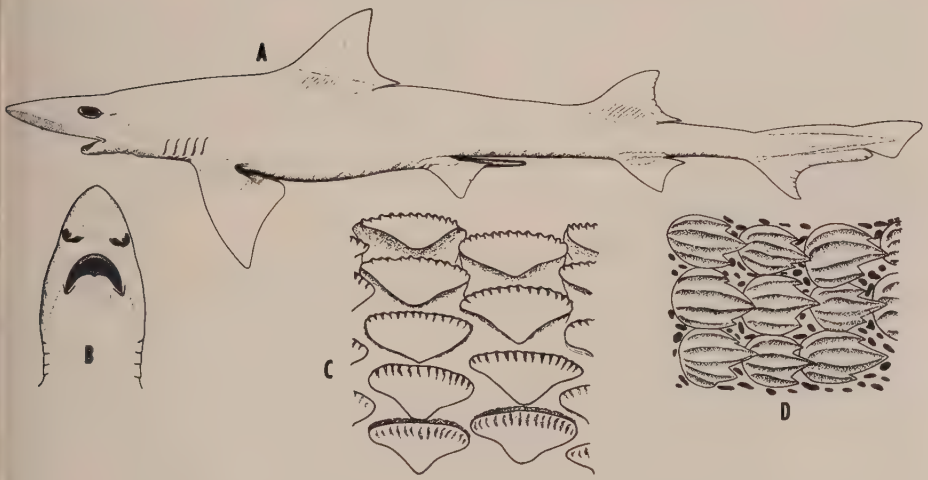


Fig. 1. *Mustelus higmani,* holotype. A—Lateral view. B—Lower side of head. C—Teeth of upper jaw. D—Dermal denticles from shoulder region. Drawn by Mildred H. Carrington.

Adult males of *M. higmani* in our series have the lower caudal lobe acuminate and in this feature differ from all *Mustelus* except the Pacific *M. lunulatus* and the Atlantic *M. norrisi.* The pointed lower caudal of all three species may be a characteristic only of the adult males as it appears to be in *higmani.* A close relationship between *higmani* and *canis* is suggested by their similarities in head, body, and fin shapes. These characters set them apart from *norrisi.*

Our material shows some variation in the relative positions of the pectoral and first dorsal fins in *M. higmani.* In most of our specimens the origin of the first dorsal is in advance of the free inner angle of the pectoral but posterior to the axil of the pectoral. However, some have the first dorsal origin directly over the angle of the pectoral and one has the dorsal origin posterior to it. Most of our specimens resemble the type in having the base of the second dorsal fin about four-fifths as long as the base of the first dorsal but we have one specimen in which the two bases are of equal length.

Although the color of the new species is usually light gray without markings, some individuals collected off British Guiana were noted to be golden yellow in life. Such a golden anomaly has been observed also in small hammerhead sharks, *Sphyrna tudes,* from the same area. This color fades in preservation. Also some specimens of *M. higmani* after preservation show the white ventral color extending dorsally along the edges of the snout.

The teeth of *M. higmani* have more prominent basal ridges than the teeth of other species of *Mustelus* examined. These ridges, although not noted in many of the earlier descriptions and accounts of the genus, are present in some species of *Mustelus* other than *higmani,* perhaps being more notable in the young of other species. We find no indication however, that the presence or strength of the ridges in *M. higmani* is related to size or sex.

In combination, the lack of spots or markings, the small size, three-pointed denticles, well-developed lower caudal lobe (usually acuminate in adults), broad pectorals with straight distal margins in young specimens, and the regularly tapering head region not abruptly narrowed at the nostrils suffice as characteristics for the identification of *M. higmani.*

*Geographical distribution of* M. higmani *and related species.*—The new species is known only from the collections previously mentioned, made on the continental shelf from 9°58′N lat., 61°11′W long., off the coast of eastern Venezuela east of Trinidad, to 2°08′N lat., 48°14′W long., off the coast of Brazil, or, more simply, between the

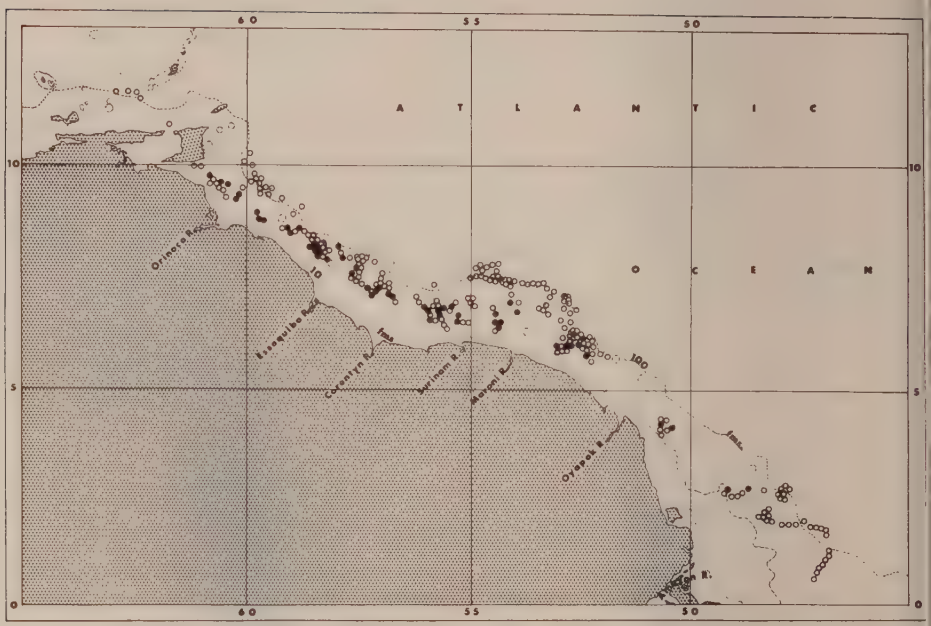


Fig. 2. Approximate locations of 253 trawling stations off the coasts of Venezuela, the Guianas and Brazil made by the Bureau of Commercial Fisheries exploratory fishing vessel *Oregon*. Solid circles, some superimposed, show locations of trawl tows producing *Mustelus higmani*.

mouths of the Orinoco and Amazon rivers (Fig. 2). The shallowest capture of which we have record was in 8 fathoms and the deepest capture in 55 fathoms.

Puyo (1949) remarks that he has not seen a *Mustelus* from the Guiana coast but included *Mustelus canis* as a probable element of the fauna of French Guiana on the basis of reports of its occurrence on the coasts of Brazil, Trinidad, Barbados, and Cuba. This makes us suspect that *M. higmani* is not ordinarily taken by hook and line fishing and supports some small evidence from our collections that it is usually absent from beach areas, river mouths and estuaries, and from coastal water in depths less than 8 fathoms. Evidently the species has not been available to earlier collectors because trawl fishing has only recently been carried out off the Guiana coasts. Collections of sharks made by French collectors in the vicinity of Cayenne are quite comprehensive and the absence of *M. higmani* from them is understandable only if specimens were not readily available to the gear in common use.

Knowledge of the distribution of western Atlantic *Mustelus* is very sketchy. The group, as reviewed by Bigelow and Schroeder (1940), includes one white-spotted species from the coast of Argentina, one dark-banded species, *M. fasciatus*, from the South American coast, and three plain-colored species or unmarked species. We can disregard the white-spotted and the dark-banded species since they should not be confused in identification and may be considered as belonging to a separate section of the genus. The plain-colored species are *Mustelus canis* (Mitchill), *M. norrisi* Springer, and *M. schmitti* Springer. The status of *M. schmitti* is uncertain. It is a little-known form described from a few specimens from the coast of southern Brazil and from the coasts of Uruguay and Argentina. It differs from *M. canis* only in minor details. Bigelow and Schroeder (1948) and Barcellos (1961) reported *M. canis* positively from southern Brazil and for consideration of the distribution of the plain-colored forms here, it seems best to ignore *M. schmitti*.

A simplified outline of the distribution of the plain-colored *Mustelus* in the western

Atlantic from presently available records shows *M. canis* to be common, at least locally, in the temperate belts of both the northern and southern hemispheres, with scattered occurrence in the West Indies; *M. norrisi* to occur only in the approximate vicinity of the two tropics, Cancer and Capricorn; and *M. higmani* to be approximately equatorial.

We have already noted that *M. higmani* is readily available to trawling gear but appears not yet to have been taken on hook and line. The reverse applies to *M. canis*. It is especially vulnerable to hook and line fishing. It is remarkable that *M. canis* was regularly caught on set lines by commercial shark fishermen using 7-inch hooks made of ⅜ inch diameter steel whenever lines were set in areas of know abundance, as off the Carolinas or off the Mississippi Delta. The irregular, localized occurrence of *M. canis* is illustrated in its distribution off the southeastern United States. It is commonly taken by snapper fishermen from offshore banks of the northern and western parts of the Gulf of Mexico but is practically unknown inshore. It is absent either inshore or offshore around peninsular Florida. It is sometimes taken in large numbers by trawlers working off the Virginia Capes but is rarely caught by shrimp trawlers in the Gulf of Mexico even in localities where it may be taken readily on hook and line.

North of the Equator, *Mustelus norrisi* is known only from the southwestern coast of Florida and the Florida Keys area. Very large numbers, all adult males, are taken by beach seines during late spring runs along the coast between Naples and Englewood, Florida. A few others, mostly gravid females, have been taken by hook and line fishing near shore or from saline estuaries. Some have been taken in the Tampa Bay area (V. G. Springer, 1961). From the numbers of males appearing in spring runs it would appear that the species is common. It is interesting, therefore, that no specimens have been collected by the Oregon or other exploratory fishing vessels in fishing with a wide variety of gear around the supposed center of abundance. *M. norrisi* is known from the southern hemisphere from two immature specimens about 445 mm long (see Bigelow and Schroeder, 1940) from Rio de Janiero. We have re-examined these specimens and find no reason to doubt that they are *M. norrisi* as the species is understood now.

Insofar as the records show distribution, there is no overlap in the ranges of the ranges of the three species, *canis, norrisi,* and *higmani.* Reports of *Mustelus* from Trinidad by Fowler (1916), from Curaçao by Metzelaar (1919), and from Barbados by Puyo (1949) appear, from measurements given for specimens, to be correctly designated as *canis.* At least, the specimens mentioned are much too large to be *higmani.* The capture of *Mustelus* was not specifically mentioned by Whiteleather and Brown (1945) in their report of fishes taken in the Gulf of Paria with various gears. In reporting results of shark fishing in the vicinity of Trinidad, Springer (1949) recorded 20 species of sharks taken by hook and line fishing from the vessel *Sachem,* but *Mustelus* was not among them.

*Natural history notes on* Mustelus higmani.—Data on the lengths of specimens have been grouped and summarized in Table 2. The longest embryo collected was 240 mm and the shortest free-swimming individual was 213 mm in total length. Males were sexually mature at about 425 mm and females at about 475 mm. The longest male collected was 585 mm and the longest female 635 mm (about 25 inches).

Of 123 females taken by the Coquette and regarded by Higman as being adults, 106 were gravid. Our collections do not show a clear seasonal cycle in the production of young since both small and large embryos were collected in each month from June to September. Such a cycle may exist however, especially if the gestation period is short. We have records of only six sets of embryos from the month of November and these are all large.

Gravid females carried 1 to 7 embryos, most commonly 3, 4, or 5. Sex was determined for 247 of the 449 embryos collected. Of these, 121 were males and 126 females. Catches of adults in single trawl hauls were sometimes all of one sex, indicating some segregation into schools by sex. For this reason, the total numbers of the sexes given in Table 2 should not be regarded as indicating the ratio of the sexes in an adequate sample of the population. One specimen recorded by Thompson but omitted from tabulation was a 465-mm individual with mature testes but no trace of claspers.

TABLE 2. LENGTH FREQUENCY OF *Mustelus higmani* SPECIMENS COLLECTED BY THE COQUETTE AND OREGON

| Length Group in mm | Number Embryos | Immature Males | Immature Females | Adult Males | Adult Females |
|---|---|---|---|---|---|
| 5– 50 | 128 | – | – | – | – |
| 51–100 | 113 | – | – | – | – |
| 101–150 | 81 | – | – | – | – |
| 151–200 | 86 | – | – | – | – |
| 201–250 | 41 | 4 | 5 | – | – |
| 251–300 | – | 5 | 1 | – | – |
| 301–350 | – | 4 | 6 | – | – |
| 351–400 | – | 1 | 17 | – | – |
| 401–450 | – | – | 16 | 10 | – |
| 451–500 | – | – | 20 | 41 | 15 |
| 501–550 | – | – | – | 56 | 85 |
| 551–600 | – | – | – | 18 | 45 |
| 601–635 | – | – | – | – | 11 |
| Total | 449 | 14 | 65 | 125 | 156 |

Higman examined the stomachs of 74 specimens. Fifty-four of these had identifiable food remains as follows:

30 stomachs contained stomatopods
17 stomachs contained brachyuran crabs
11 stomachs contained hermit crabs
7 stomachs contained shrimp
5 stomachs contained fish
2 stomachs contained squid
1 stomach contained pieces of a coelenterate.

All of the dogsharks were caught on mud bottom or on bottom having mixed sand and mud or shell and mud.

*Selection of catch by mesh size and net size.*—Detailed records of the catches in 434 trawl tows made by the COQUETTE were furnished by Higman. Of these tows, 395 were 15-minute tows with try-trawls, that is, small shrimp nets. The try-trawls had headrope lengths of 8.5, 10.5, and 13.5 feet and were constructed throughout with cotton twine with mesh size 1¾-inch (stretched measure). We assume that the try-trawls, following standard practice in the Gulf of Mexico shrimp fishery were towed at approximately 5 knots. About every 10 tows, but not at exactly regular intervals, tows were made with a larger shrimp trawl having a headrope length of 69 feet, constructed of 2¼-inch (stretched) mesh cotton webbing. Tows with the large net were for 1½ to 3½ hours and we assume from data on the shrimp fishery that towing speeds did not exceed 2½ knots.

Of 395 tows made with the small nets, 5 caught *Mustelus*, all very small ones. Three were 9 inches long, one was 11½ inches long, and one was 12 inches long. Of 39 tows with the large net, 29 tows produced 188 *Mustelus*, the smallest 13 inches long.

It is possible that the larger mesh size in the large nets permitted the escape of *Mustelus* under 13 inches, but our series is too small for confidence in this. Furthermore, collections in the same general area made later by the OREGON using nets with 2½-inch mesh did include four *Mustelus* 8 to 11 inches long. It is obvious, however, that the small nets were not effective in catching *Mustelus higmani* over 13 inches in length.

That the width of the trawl opening limits the size of the fish to be caught with a trawl is a generality known to trawl fishermen. In the data obtained by Higman, sizes of teleosts were indicated only by a range of lengths and the data could not easily be analyzed. Nevertheless the data do show a limit of about 13 inches for fishes of all kinds, as well as for *Mustelus*, caught by the small nets. The limits probably would vary with the speed of towing and with other factors. Fortunately, the size selectivity limit for the large nets used in the surveys appears to be greater than the maximum size of *M. higmani* although their effectiveness in catching adult *M. canis* 3 to 5 feet long would be questionable.

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## The African Cichlid, *Tilapia heudeloti* Dumeril, in the Commercial Fish Catch of Florida[1]

*Tilapia heudeloti*, a native of west Africa from Senegal to Gabon, has been imported into the United States by tropical fish dealers and is well known to aquarists (Axelrod and Schultz, 1955). It was reported by these authors as *Tilapia macrocephala* (Bleeker), which is a synonym of *T. heudeloti*. Evidence has been accumulating over the past few years that this species has become well established in the Hillsborough Bay area on the west coast of Florida.

The first record of *Tilapia heudeloti* in Hillsborough Bay is based on a 204-millimeter specimen (standard length) caught in a gill net during late summer, 1959, between Mangrove Point and the Alafia River. This fish was one of two taken by mullet fishermen. The specimen is in the collection of the Florida State Board of Conservation Marine Laboratory at St. Petersburg. All subsequent records of which we have knowledge have come from points in this area (mainly Bullfrog Creek) and associated tributaries.

According to the owner of a seafood market in Tampa, tilapia were first noticed in gill-net catches during 1958. He noted that they became common in catches during early 1959 when four or five, or occasionally 10 to 15, specimens were obtained in a day's fishing. At this time he began to market the species. Catches usually occurred during the winter, and at times there were periods of 2 or 3 months when no specimens were caught.

A specimen which appeared to be a spent female was obtained from the commercial fish catch on March 27, 1960. On April 8, 1960, an attempt was made to collect tilapia along the shore and in tidal inlets in the area from which the commercial fishermen had made their catch. A 100-foot minnow seine and rotenone were used, but no specimens were obtained. On April 28, 1960, 4 of 10 specimens caught by commercial fishermen were examined. Two were females with mature or nearly mature eggs, and the other two were males. The oral cavities of both males were filled with eggs. According to Axelrod and Schultz (1955), *T. heudeloti* is known to be a mouth breeder.

Between May 1960 and October 1962, no special efforts were made to obtain information on tilapia. However, a monthly seine station was established for another study during December 1961 in a tributary of Bullfrog Creek about ½ mile above its entrance into Hillsborough Bay. The water depth at this station varies from 2 to 3 feet depending on the tide. The bottom is composed of fine mud and sand. The shore, except for one small clearing, is surrounded by mangrove thickets.

In the seine collection of October 1962 (water temperature 23.7° C.; salinity 8.22 p.p.t.; pH 7.63) from the Bullfrog Creek tributary were two small specimens of *Tilapia heudeloti* measuring 50 and 53 millimeters, standard length. The following month (water temperature 14.8° C.; salinity 1.58 p.p.t.; pH 7.80) one specimen measuring 64 millimeters was collected and another seen. The

[1] This report was initiated while the senior author was in the employ of the Florida State Board of Conservation Marine Laboratory, and it constitutes contribution number 71 of that institution.

three specimens are deposited in the United States National Museum.

In December 1962 the seafood dealer was again interviewed, and we were told that he had noticed a definite increase in catches of tilapia during the past two years. He estimated that in 1962 he had marketed between 3,500 and 4,500 pounds (presumably all *T. heudeloti*) at 25 cents a pound under the name African sunfish. Public acceptance appeared to be good, and the flavor is described as being similar to that of freshwater sunfish (*Lepomis* sp.). Apparently there is only one major supplier of tilapia in the area at the present time.

Gulf Hatcheries, a tropical fish supply house at Palmetto, Florida, reported that in the past two years (1961–62) tilapia have become firmly established at Ruskin, situated on a tributary of the Little Manatee River just south of Mangrove Point.

During December 1962, Florida was subjected to a record cold wave. The lowest water temperature for which we have a record was from Old Tampa Bay; 9.6° C. on December 13. The seafood dealer reported receiving 1,553 pounds of tilapia from nearby Bullfrog Creek between December 13–17. According to him the fish were sluggish but alive when caught. Three decomposing tilapia and numerous living adults were seen by the junior author in the Bullfrog Creek area on December 17, but there was no evidence of a massive kill. Apparently *T. heudeloti* can survive the low temperatures to which the State of Florida is occasionally subjected.

It is probable that one or more of the numerous tropical fish hatcheries in the area around Hillsborough Bay were the original source of *Tilapia heudeloti*. Some of these hatcheries maintain large outdoor ditches in which tropical fishes are reared. It is possible that individuals escaped or were released into tributaries of Hillsborough Bay. However, the possibility that the species was released by some aquarium hobbyist cannot be eliminated. The senior author recalls mention of one tropical fish dealer in the area going out of business and releasing his entire stock in local streams.

On the basis of the above information, it is evident that *Tilapia heudeloti* is now a member of the Florida fish fauna. It is not possible at the present time to predict the effect, if any, which the presence of this species will have on the indigenous fauna. Examination of stomach contents of adult specimens produced only unidentifiable vegetable material. On this basis no competition for food with the local sport or commercial fishes would be expected, as none are known to feed primarily on plants.

ACKNOWLEDGMENTS

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*Division of Fishes*
*U. S. National Museum*
*Washington 25, D. C.*
*and*
*U. S. Bureau of Commercial Fisheries*
*Biological Station*
*St. Petersburg Beach, Florida*

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# HISTOLOGY OF THE REPRODUCTIVE SYSTEM OF THE SOFT-SHELL CLAM (MYA ARENARIA)

ALDEN P. STICKNEY

*Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine*

# HISTOLOGY OF THE REPRODUCTIVE SYSTEM OF THE SOFT-SHELL CLAM (MYA ARENARIA)

ALDEN P. STICKNEY

*Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine*

In many kinds of experimental work with marine organisms, a means of inducing them to spawn under laboratory conditions is often essential. Although many species of lamellibranch molluscs spawn readily in response to suitable stimuli, the soft-shell clam (*Mya arenaria*) is more refractory, responding poorly and erratically to the commonly used techniques of stimulation. To gain a better understanding of the spawning mechanism in *Mya*, a detailed study of the morphology and histology of its reproductive system was undertaken. Although the anatomy of *Mya* was described in some detail by Vlès (1909), only a few lines were devoted to the reproductive organs. Coe and Turner (1938) described the reproductive system more thoroughly, but less attention was given to the accessory organs than to the gonad itself. Furthermore, the discussion of the system was presented from a developmental viewpoint and dealt primarily with immature animals. The purpose of the present paper is to describe the morphology and histology of the reproductive system as a whole, with particular emphasis on structures other than the gonad.

Because *Mya* differs from many other species in its responsiveness to artificial spawning stimuli, any peculiarities in the morphology of its reproductive system must be examined in the light of their possible relationship to spawning activities. For this reason, comparative studies were made of two additional species: the surf clam, *Spisula solidissima*, and the hard clam, *Mercenaria mercenaria*, to determine whether Mya differed significantly in the morphology of its reproductive system. Observations on the spawning activities of these species were also made to learn what aspects of function might correspond with peculiarities in structure.

## Methods

The information presented in this paper was based on the following sources:

(1) Several hundred histological preparations of the gonad tissue of *Mya arenaria*, representing all seasons of the year, were examined.

(2) Gross dissections and examinations were made on fresh specimens of *Mya arenaria*, *Mercenaria mercenaria* and *Spisula solidissima*.

(3) Living specimens of these three species were held in aquaria and their spawning activities observed.

(4) Serial sections of tissues fixed in Bouin's fluid were made through the region of the genital papillae of 13 randomly selected specimens of *Mya*, 5 of *Spisula* and three of *Mercenaria*. These sections were stained with haematoxylin and eosin and mounted on slides.

Photographs were made of various structures in the histological preparations and reconstructions in the form of sketches were made to clarify the spatial relationships of the structures.

Spawning of the living specimens was artificially induced by a cyclic fluctuation in water temperature, or in a few cases by injecting 1 ml. of 0.1 N ammonium hydroxide into the gonad through the mantle strap.

## Results

In general arrangement, the reproductive system of *Mya* is similar in both sexes. The gonads are paired organs consisting of highly ramified tubules bearing numerous terminal and lateral alveoli. In a well-nourished, ripe individual these alveoli are closely packed and fill much of the visceral mass. The tubules of each gonad, by a series of confluences, eventually merge into a pair of gonoducts (Fig. 1)

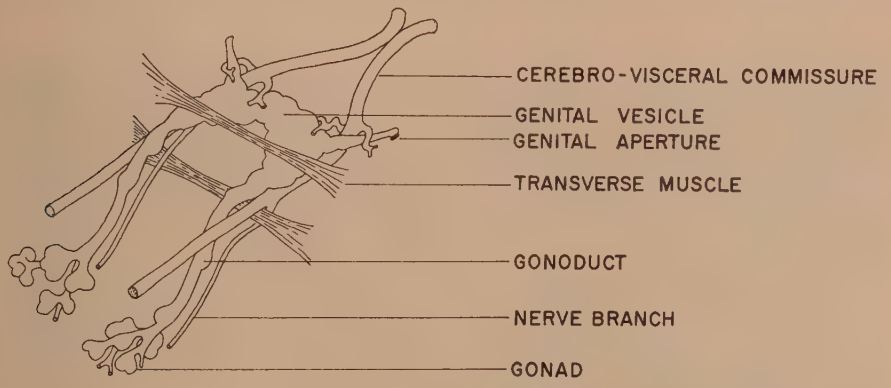


Figure 1. Semi-diagrammatic reconstruction of the reproductive system and associated structures in *Mya arenaria.*

which lead caudad and dorsad towards the region of the genital apertures. The apertures are situated on tiny papillae located on either side of the dorsal apex of the visceral mass (Fig. 2), just anterior to the foot retractor muscle. According to Vlès (1909), the gonads remain isolated from one another throughout the system, so that ink injected into one of the genital apertures will permeate the genital organ on one side of the clam only. While this mutual isolation seemed to be true in some of the individuals which I examined, in most specimens the gonoducts were joined in a common chamber or vesicle (Figs. 1 and 3), lying between and slightly anterior to the genital apertures. The vesicle is often bilobed, suggesting a tendency toward separation. Leading caudad and laterally from this vesicle are two short ducts (referred to henceforth as the "terminal gonoducts") which lead to the genital apertures. The apertures, opening into the dorsal pallial cavity, are in the form of slits curving from the termini to the lateral sides of the papillae.

The paired nerve trunks of the cerebro-visceral commissure pass directly under the terminal gonoducts, giving off many small branchlets which invest the con-

nective tissue in this region. A larger branch from each of these nerve trunks follows the gonoduct from the genital vesicle deep into the gonad itself. The wall of the visceral mass contains abundant muscular tissue; connecting these walls transversely are numerous bands of muscle fibers which pass through the gonad.

The histological structure of the gonad alveoli has been described by Coe and Turner (1938). These alveoli consist of a thin basement membrane or wall surrounding a group of large, transparent follicle cells, which may fill the alveolus solidly, or may separate in the center to form a lumen. The gametes arise from the basement membrane between the peripheral follicle cells. The gonoducts and their branches resemble the alveoli in histological structure, except that the large, transparent cells tend to be more elongate, oriented perpendicularly to the basement membrane, and a lumen is always present. Gametes are also proliferated from the basement membrane of the gonoducts, although less abundantly than in the alveoli. In some specimens the transparent cells lining the gonoduct are reduced in size and appear to be disintegrating. Where this process is taking place, clusters of clear droplets appear in the lumen, suggesting holocrine secretory activity.

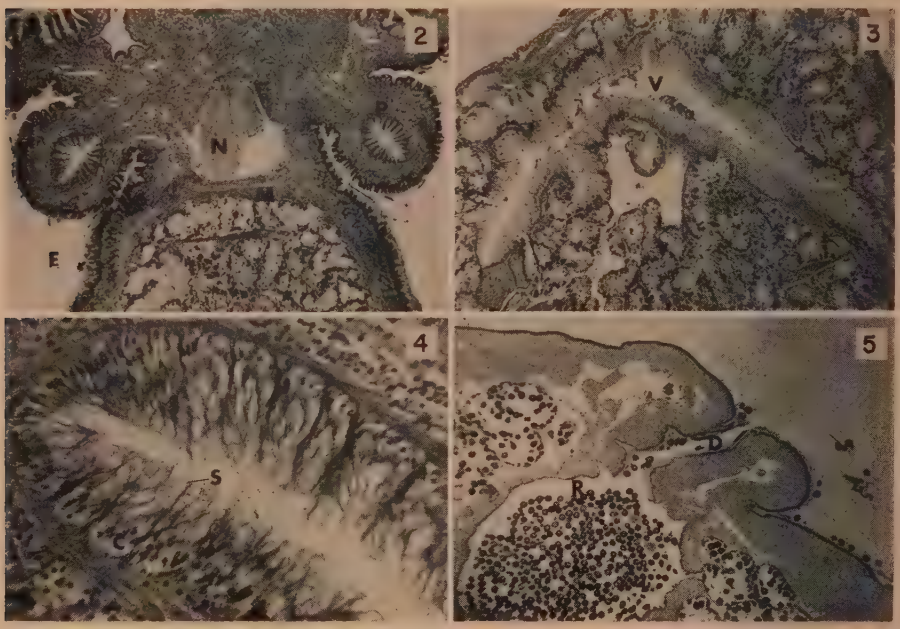


FIGURE 2. Cross-section through the visceral mass of *Mya arenaria* at the level of the genital papillae. Papillae (P), cerebro-visceral nerve commissures (N), transverse muscles (M) and dorsal pallial chamber (E) are indicated. × 35.

FIGURE 3. Cross-section through the visceral mass of *Mya arenaria* at the level of the genital vesicle (V). × 35.

FIGURE 4. Cross-section of terminal gonoduct of *Mya arenaria* taken through genital papilla, showing both ciliated columnar (C) and non-ciliated "secretory" cells (S). × 300.

FIGURE 5. Longitudinal section through genital papilla of *Spisula solidissima,* showing terminal gonoduct (D) and enlarged portion of main gonoduct (R) used as reservoir for eggs. × 25.

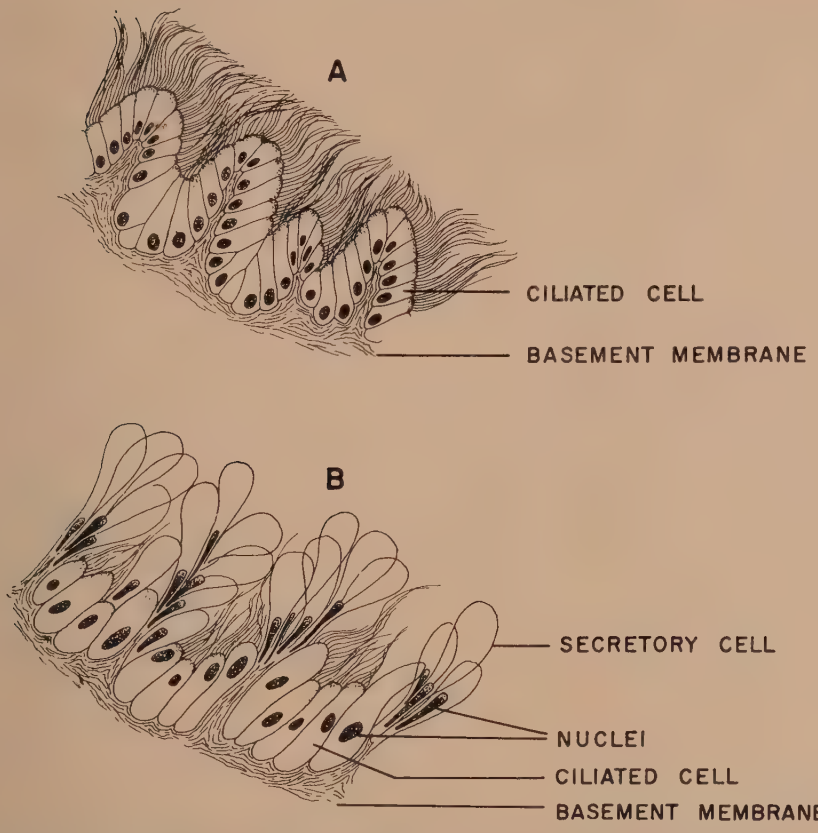


FIGURE 6. Camera lucida drawings, somewhat simplified for clarity, showing portions of the ciliated (A) and non-ciliated (B) epithelial tissues in the terminal gonoduct of *Mya arenaria*.

The tissue lining the terminal gonoducts deserves particular notice. The interior walls are wrinkled with longitudinal ridges of connective tissue upon which rests an epithelium of columnar and other cells, the nature and arrangement of which is variable. In the simplest case, all are ciliated columnar cells with prominent elliptical nuclei (Fig. 6A). The cytoplasm stains lightly with eosin, more intensely so near the ciliated ends of the cells. In a somewhat more complex arrangement, the longitudinal ridges may extend farther into the lumen to form thin folds rather than simple ridges. The ciliated columnar cells on these folds become or are replaced by elongated, non-ciliated cells with bulbous ends containing a granular cytoplasm. In what appears to be an advanced stage of this development, the bulbous ends become very prominent and more transparent, and groups of them on the crests and sides of the folds of connective tissue suggest, in section, clusters of fruit on a stalk (Figs. 4 and 6B). Groups of these specialized cells alternate with groups of ciliated cells, or may sometimes replace them entirely. Many

intermediate arrangements between the extremes of simple ciliated columnar epithelium to the highly modified bulbous cells can be found in different individuals. The arrangement may differ between the two terminal gonoducts of the same individual.

The function of the ciliated cells is undoubtedly to assist in the extrusion of gametes from the genital aperture. That of the other cells is uncertain, but their appearance suggests a secretory function. Because of the variation in the arrangement and nature of this epithelial tissue, it is possible that a cyclic transition occurs in a manner similar to that in tissues of certain reproductive organs in higher animals. However, no relationship was apparent between the condition of the gonoduct epithelium and the sex or the stage in the seasonal reproductive cycle of the clams examined.

The reproductive systems of both *Mercenaria*, described by Loosanoff (1937a, 1937b), and *Spisula* are similar in many respects to that of *Mya*. One essential point of difference is the lack in the former species of the large follicle cells characteristic of *Mya*. Also, both *Mercenaria* and *Spisula* possess more abundant muscular tissue throughout the visceral mass. The genital vesicle of *Mya*, described above, seems to be less well defined in *Mercenaria* or *Spisula*, but these species do have greatly enlarged portions of the gonducts which occupy the same region.

The lining of the terminal gonoduct in *Mercenaria* is similar to that of *Mya*. On the other hand, that of *Spisula* is quite different. In this species the epithelium is a simple and relatively smooth layer of ciliated columnar cells, differing little from the ciliated epithelium on the exterior surface of the papillae (Fig. 5). Although some longitudinal folding is apparent, the prominent alternating ridges and furrows characteristic of *Mya* are absent.

## Discussion

There are certain aspects of observed spawning processes in clams which appear to be related to the morphology of the reproductive system and which suggest the function of some of the structures observed in histological preparations. One of these aspects is the relative slowness of response to artificial spawning stimuli characteristic of *Mya*. Not only does this species respond much less readily than either *Mercenaria* or *Spisula* at any time, but its response declines noticeably toward the latter part of the spawning season. In 1961, when the laboratory spawning experiments were conducted, the period during which *Mya* could be found in a predominantly ripe condition lasted from late May through July, and some ripe individuals could be found even in mid-August. It was chiefly during the month of June, however, when this species responded most readily to spawning stimuli. Even during this brief period, the frequency at which spawning could be induced declined steadily during the period that any group of clams was held under observation. After the first week in July, no responses could be obtained, either from clams already under observation or from freshly dug specimens, even though many of them were still apparently ripe. On one occasion a group of clams expelled large quantities of blood and tissue cells, indicating a mechanical spawning reflex in response to the stimuli, but shed no gametes.

Examination of several hundred sections of *Mya* gonad tissue, representing all seasons of the year, has shown that rarely were ripe ova strongly preponderant in

the ovaries. Usually, even in "ripe" individuals, eggs were present in all stages of development. It is difficult to understand, therefore, how a clam can emit several million eggs in a few minutes, as commonly occurs during spawning, if these must be freed directly from the ovaries.

What appears to be more likely is that eggs are accumulated before spawning in a reservoir from which they can be extruded *en masse*. This situation can be readily observed in both fresh and histologically prepared ripe specimens of both *Mercenaria* and *Spisula* (Fig. 5), where enormous numbers of ova (or spermatozoa) are accumulated in the enlarged portions of the gonoducts in the posterodorsal region of the visceral mass. It seems evident that the genital vesicle of *Mya* is homologous to the enlarged oviducts of the other two species and serves as a reservoir for the accumulation of gametes prior to spawning. By exerting pressure with a finger on the visceral mass of a ripe *Mya* in the locality of this vesicle, one can force from some individuals a limited quantity of gametes through the genital apertures. Once this quantity has been extruded, further pressure produces no more gametes, even though the ovaries are still replete.

If ripe gametes are accumulated in a reservoir prior to spawning, one might expect to find them in serial sections through the gonoducts and genital vesicle. Although only three of the serially sectioned specimens were ripe, one of these did contain substantial numbers of accumulated ova in the genital vesicle. Nevertheless, such accumulation was far less prevalent or exuberant in *Mya* than in either *Mercenaria* or *Spisula*. This fact could account for the relatively poor response of *Mya* to spawning stimuli if an accumulation of ripe gametes in a reservoir is a necessary precedent to spawning.

An extension of this argument may also help explain why apparently "ripe" clams in June spawn more readily in the laboratory than apparently "ripe" clams in July or August. Apparent ripeness is merely a measure of the abundance of ripe gametes in the gonad at a single moment. It indicates nothing about the rate at which they are being proliferated; yet the frequency of occurrence of clams with full reservoirs must certainly be dependent on the rate of gamete production. If the gamete production rate declines later in the season, response to spawning stimuli should decline accordingly.

Comparative studies of the three species have revealed another relationship between spawning physiology and morphology which, although its significance is not clear, warrants attention. In every experiment where *Mya* was induced to spawn in the laboratory, the eggs were shed with the nucleus membrane dissolved, that is, in the initial stages of meiosis. In this respect, *Mercenaria* is similar to *Mya*. On the other hand, *Spisula* releases eggs with the nucleus intact, and the initiation of meiosis ("activation") occurs after the sperm has penetrated the egg (Allen, 1953; Costello *et al.*, 1957). This is true of other lamellibranchs, and the American oyster (*Crassostrea virginica*), although not included among the species which I examined, is a pertinent example.

Apparently related to these differences is the fact that the eggs of *Spisula* and *Crassostrea* can be excised artificially from the ripe ovary and readily fertilized by placing them in clean water with a little sperm, after which they will develop normally (Costello, *et al.*, 1957; Galtsoff, 1937). Viable eggs can seldom be obtained in this manner from either *Mercenaria* (Loosanoff, 1953) or *Mya*. *Mya*

and *Mercenaria,* the eggs of which are "activated" before spawning, and which cannot be fertilized successfully unless so "activated," both have the complex epithelium of the terminal gonoduct described earlier. *Spisula* and *Crassostrea,* which release their eggs before "activation," and from which viable eggs can be excised directly from the ovaries, have a relatively simple epithelium lining the gonoduct. This is shown for *Spisula* in Figure 7; Galtsoff (1961) shows a similar figure for *Crassostrea.*

Obviously, further investigation is required to clarify this relationship, and to determine the extent to which it applies to other species of lamellibranch.[1] Also, the examination of more individuals, collected in various stages of their seasonal reproductive cycle, should provide clues as to the role played by the epithelial cells in the terminal gonoduct.

## Summary

1. The reproductive organs of *Mya arenaria* consist of paired alveolar gonads, connected by paired gonoducts to a (usually) common vesicle. From the vesicle, a pair of short terminal gonoducts lead to the genital apertures.

2. The region occupied by the vesicle, terminal gonoducts and genital apertures is invested with muscular and connective tissue and is highly innervated with branchlets from the cerebro-visceral commissures which pass through the region. Paired branches from these nerve trunks also follow the main gonoducts into the gonad.

3. The terminal gonoducts are lined by longitudinally furrowed epithelium of ciliated columnar cells. In many individuals groups of these cells alternate with groups of non-ciliated, elongated cells with bulbous tips, apparently secretory in function.

4. Evidence is cited to show that sex products are accumulated in the genital vesicle prior to spawning. Homologous structures in two other species of lamellibranch are described which serve the same purpose.

5. An apparent relationship is shown between the time and site of egg activation and the nature of the epithelium of the terminal gonoduct of four species of lamellibranch molluscs.

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[1] Since the completion of this manuscript, I had occasion to examine sections through the genital papilla of the common mussel (*Mytilus edulis*) and found that the lining of the terminal gonoduct of this species is very similar to that of *Mya. Mytilus,* like *Mya,* also sheds its eggs after nuclear breakdown.

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## 2. Employment of Submarines for Scientific Research

During the two thousand years of their existence, submarines have steadily evolved as weapons, and only in very recent years have their research capabilities been utilized. Actually there exist a number of extremely important research missions for which a submarine is the ideal tool. These missions relate to the exploration and development of the sea's living resources such as fish, shellfish, and algae; its mineral deposits including coal, oil, and metals; and numerous oceanographic features, such as the ocean currents, which have profound effects on man's activities ashore.

Surface ships are inherently limited as oceanic research tools. Samples obtained by their use are acquired in a blind, groping manner; seasonal storms or ice exclude them from operating in many areas; and their motion often precludes the use of such delicate instruments as balances and microscopes. Submarines are not beset by these problems. They can place man in intimate contact with almost any oceanic feature he wishes to observe, eliminating blind sampling. With modern propulsive means, they can remain submerged beneath the most severe storms or ice. At such times they are sufficiently stable to permit many types of delicate research.

The vehicles used for underwater research today cover a broad range of designs and capabilities. At one end of the scale are devices which simply relieve divers of the task of propulsion. Farther up the array is a series of midget submarines suitable for short, shallow dives. More elaborate vessels have been built for deep exploration, one such craft already having reached the bottom of the Marianas Trench. The most complex research vehicle is Russia's converted naval submarine *Severyanka,* which is being used for extensive studies of fish behavior and gear performance.

The United States Department of the Interior has planned a submarine to undertake research missions for two of its branches, the Bureau of Commercial Fisheries and the Bureau of Mines. This vessel will be used for the study of fish behavior, oceanic productivity, oceanography, bioacoustics, gear performance, and other fishery missions, and in addition for visual, magnetic, and radiological prospecting and drilling for mineral resources. The vessel is envisioned as being about 150 feet in length, and capable of 20 knot speeds and 1,000 foot dives. It is hoped that automation will permit manning it with a relatively small crew, and that the use of modern propulsive power will allow extended periods of submergence. A large well-equipped laboratory is planned to accommodate the needs of 10 scientists.

DONALD W. STRASBURG
Bureau of Commercial Fisheries,
Biological Laboratory

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# The Diet and Dentition of *Isistius brasiliensis*, with Remarks on Tooth Replacement in Other Sharks

DONALD W. STRASBURG

**Twenty-two central Pacific specimens of the pelagic shark *Isistius brasiliensis* were captured by midwater trawls and plankton nets operated at night. Eight specimens were dissected; their anatomy was typically squalid and their diet consisted principally of squid. Some stomachs contained swallowed mandibular teeth in quantities sufficient to indicate that the entire mandibular dentition was shed as a unit. One *Isistius* had both the displaced and replacement dentitions in place in the lower jaw. Tooth measurements suggested that there are 15 complete replacements of the mandibular dentition in the known length range of *Isistius*, 140–501 mm. There appeared to be a decrease in the number of mandibular teeth with growth.**

**The dried jaws of 13 other shark species were examined to determine how tooth replacement takes place. One species resembled *Isistius* in that it replaced all of its teeth at the same time, others constantly replaced a few teeth, while still others constantly replaced most teeth. Sometimes there were different replacement rates for the upper and lower jaws. The manner of tooth arrangement may result in some teeth blocking the replacement of others. The effects of various tooth arrangements on replacement are discussed.**

THE U. S. Bureau of Commercial Fisheries Biological Laboratory in Honolulu has sampled the epipelagic community by trawl and plankton net for several years. This effort has resulted in the capture of 22 specimens of the pelagic squalid shark, *Isistius brasiliensis* (Quoy and Gaimard). Although *Isistius* has received recent taxonomic attention (Bigelow and Schroeder, 1948, 1957; Hubbs and McHugh, 1951), there is little known about its biology. This paper reports on its diet, distribution, and manner of tooth replacement. The latter subject was also investigated for several other sharks.

Fourteen of the 22 *Isistius* are now in the collections of the U. S. National Museum, and are cited here only as distributional records. The eight remaining specimens are in the Honolulu laboratory's collections, and have been examined in some detail. Collection data for all 22 specimens are listed in Table 1, and supplementary information on three of these can be found in a report by King and Ikehara (1956).

Thanks are due the State of Hawaii Division of Fish and Game for the loan of comparative jaw material, and Everet C. Jones of the Biological Laboratory, Honolulu, for aid in identifying food organisms.

## DISTRIBUTION

The localities of capture for the 22 specimens of *Isistius* are shown in Figure 1. The

TABLE 1. CAPTURE DATA FOR *Isistius brasiliensis*

| Date | Zone Time | Latitude | Longitude | Gear | Max. Depth of Tow (m) | Total Length (mm) | Sex |
|---|---|---|---|---|---|---|---|
| 29 Sept. 1951 | 1919–1950 | 05°56′N | 150°00′W | 1-m net | 200 | 335 | ♂ |
| 2 Mar. 1952 | 2239–2309 | 02°04′S | 168°57′W | " | 197 | 165 | ♂ |
| 23 May 1954 | 1947–2110 | 04°47′N | 161°04′W | 6-ft trawl | 100 | 179 | ♀ |
| 2 June 1954 | 1942–2058 | 02°09′N | 158°16′W | " | 95 | 189 | ♀ |
| 25 Mar. 1955 | 2012–2110 | 17°30′N | 157°05′W | " | 90 | 225 | ♀ |
| 31 Oct. 1955 | 2006–2107 | 02°54′S | 113°08′W | 10-ft trawl | 318 | 361 | ♂ |
| 2 Nov. 1955 | 2003–2105 | 07°37′S | 114°48′W | " | 357 | 292 | ♂ |
| 21 Aug. 1956 | 2006–2107 | 07°52′S | 135°04′W | " | 176 | 237 | ♀ |
| 26 Sept. 1956 | 2005–2105 | 00°02′N | 159°50′W | " | 176 | 355 | ♀ |
| 22 Oct. 1957 | 0043–0113 | 09°32′S | 139°51′W | 1-m net | 140 | 175 | ♂ |
| 22 Oct. 1957 | 0401–0432 | 09°33′S | 139°50′W | " | 140 | 161 | ♀ |
| 27 Oct. 1957 | 0154–0224 | 09°17′S | 139°16′W | " | 140 | 194 | ♀ |
| 28 Oct. 1957 | 0230–0301 | 11°22′S | 139°27′W | " | 140 | 168 | ♂ |
| 3 Nov. 1957 | 0249–0319 | 06°26′S | 139°52′W | " | 140 | 201 | ♀ |
| 13 Jan. 1958 | 2006–2037 | 04°32′S | 142°49′W | " | 146 | 248 | ♂ |
| 8 June 1958 | 2052–2142 | 09°34′S | 139°52′W | " | 126 | 233 | ♂ |
| 27 Oct. 1958 | 2010–2220 | 00°01′N | 149°44′W | 40-ft trawl | 85 | 446 | ♀ |
| 2 Nov. 1958 | 2013–2158 | 00°44′S | 149°46′W | " | 85 | 249 | ♀ |
| 28 July 1960 | 1945–2145 | 22°06′N | 161°11′E | " | 157 | 383 | ♂ |
| 28 July 1960 | 1945–2145 | 22°06′N | 161°11′E | " | 157 | 382 | ♀ |
| 22 Jan. 1961 | 2045–2207 | 22°10′N | 151°21′W | " | 85 | 462 | ♀ |
| 5 May 1961 | 2104–2134 | 18°22′N | 159°01′W | 1-m net | 65 | 177 | ♂ |

species was collected only in the tropics, where it was found relatively near shore as well as hundreds of miles from land. The concentration near the Marquesas Islands represents small sharks, 161–201 mm in length, with one exception. Other small *Isistius* were collected in the vicinity of the Phoenix and Line islands, so it is possible that this shark has inshore nursery grounds. There are no indications of sexual segregation, and the sex ratio appears to be 1 : 1.

*Isistius* was captured only at night (Table 1) even though trawling and plankton collecting were done at all hours. It was the

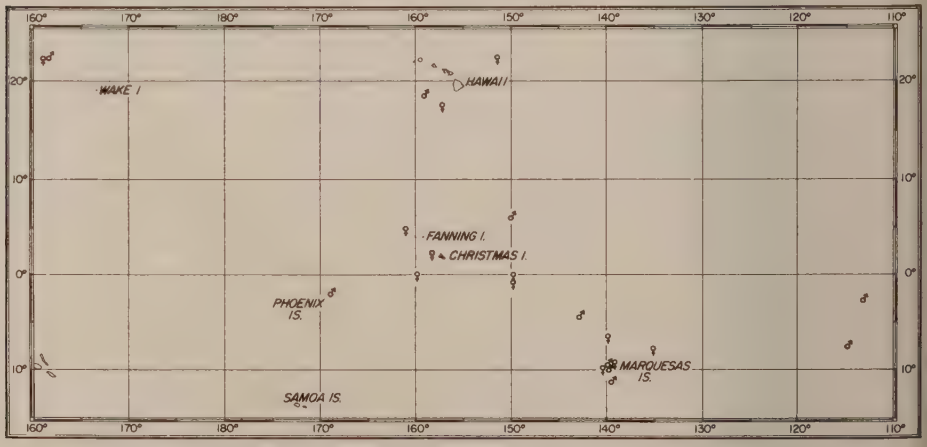


Fig. 1. Localities where the shark *Isistius brasiliensis* was captured.

largest organism taken by these slow-moving (2.5–7 knot) nets, and hence appears to be either a slow-swimmer or insensitive to the net's presence. The nets and trawls were landed on a brightly lit deck, making it difficult to observe the shark's well-known luminosity. One specimen emitted a light-blue glow, while the eyes of two others gleamed with reflected light, indicating the presence of a *tapetum lucidum*.

### Internal Anatomy

A superficial inspection of the internal anatomy was made when the *Isistius* were examined for food consumed. Five of the eight dissected specimens are females, measuring 237–462 mm in total length. In these, the ovaries are elongate paired structures lying dorsal to the stomach. The *ostium tubae* lies in the falciform ligament, and from it the paired oviducts run to the dorsal wall of the coelom and thence posteriorly to the cloaca. In the larger females the oviducts bear thick-walled shell glands anteriorly, while posteriorly they are dilated as uteri. In a 382-mm female the largest ovarian eggs are about 1 mm in diameter, and in a 462-mm specimen they measure 4.6 mm. A 446-mm female contained no embryos even though its coelom bulged with yellow yolk material prior to being incised.

The liver of *Isistius* has a rudimentary middle lobe and elongate right and left lobes which extend the length of the coelom. The stomach is a straight, relatively thin tube which is nearly smooth internally. It has a short pyloric reflexion, following which are the valvular intestine and rectum. The latter bears a tiny digitiform gland on its dorsal surface. Dissection of all *Isistius* was hindered by the very oily state of the viscera.

### Diet

Squid apparently are a common food of *Isistius*, for their remains were found in six of the eight stomachs opened. These remains consisted of beaks, pens, tentacles, and pieces of miscellaneous soft tissue. The beaks and tentacles are estimated to have belonged to squid 150–300 mm in length excluding tentacles. This is surprisingly large prey for a small shark, particularly when considered on a volumetric basis. Intact 150–300 mm squid have a volume range of 50–500 ml, as compared to 105–480 ml for the sharks which ate them (these sharks are 292–462 mm in length). On the basis of relative swimming speeds it is difficult to understand how a 480-ml shark can capture a 500-ml squid when the latter is alive. Scavenging on dead squid seems to be discredited by the high occurrence of squid in stomachs. Feeding on large prey is no doubt facilitated by the large gape and unusual jaw plicatures of *Isistius*.

A few miscellaneous items were also eaten by *Isistius*. One stomach contained a single gonostomatid fish, *Vinciguerria* sp., in excellent condition. Inasmuch as *Vinciguerria* was extraordinarily abundant at the particular trawling station, there is a possibility that it was swallowed while in the trawl. Another shark had eaten three crustaceans which bear some resemblance to caligoid copepods. Two stomachs contained fibrous matter thought to be vertebrate connective tissue. The oil which contaminated the body cavity was also found in three stomachs. These contained from 5–30 ml of clear yellow oil each.

### Tooth Replacement in *Isistius*

The most unusual items in the stomachs were the free mandibular teeth of *Isistius*

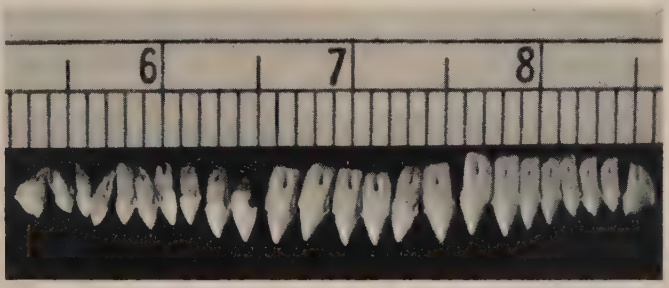


Fig. 2. Mandibular teeth recovered from the stomach of an *Isistius brasiliensis* 249 mm in total length.

Fig. 3. Double mandibular dentition in an *Isistius brasiliensis* 177 mm in total length.

itself. Three of the eight stomachs contained 27, 9, and 3 teeth, respectively. Most of the swallowed teeth were in perfect condition in the shark which ate 27, whereas most were broken in the sharks containing 9 and 3. Figure 2 shows 24 of the original 27 teeth recovered from one stomach (three teeth were mislaid when the photograph was taken).

It was first thought that if the ingested teeth were lost from the consumer's jaws, then gaps between the functional teeth would indicate their former places there. No gaps were found in the jaws of the three tooth-consumers, however, nor were there any in the five other available *Isistius*. The only dental imperfection seen was a single broken tooth tip in the shark which had eaten 27 teeth.

Cannibalism on other *Isistius* could also result in teeth being eaten. If cannibalism occurred, one would expect both functional and replacement teeth to be consumed. The latter would be distinguishable from the former by their greater size (see below). After close study, the 27-tooth set was arranged as a single dental series consisting of a mesial tooth, the unique lateral teeth, and other right- and left-handed members as shown by Bigelow and Schroeder (1948: 510). This series contains only one size group of teeth, indicating that cannibalism had not taken place.

The probable manner in which the teeth were ingested is suggested by Figure 3. This depicts a 177-mm *Isistius* which was captured at the time of tooth replacement. Unlike the other specimens at hand, it has two erect rows of mandibular teeth, one firmly attached near the crown of Meckel's cartilage, the other loosely set in the outer gums, about 1.3 mm posterior to the first. Both sets are in perfect condition, the broken tip visible in the photograph being only an artifact.

It is clear that the second set of teeth has been displaced by the first, and is being shed as a complete unit. This type of replacement is known for *Squalus*, but heretofore has been only hypothesized for *Isistius* (Bigelow and Schroeder, 1948:65–6). The individual teeth are still interconnected at their bases, so that if one tooth is touched, the whole row moves. At the symphysis the teeth can be moved 0.4 mm laterally and 0.8 mm anteroposteriorly. Although the bonds between the teeth and the mandible are still strong, the seizure of tough food would break them and free the teeth. Some would probably be swallowed with the food, and the digestive processes

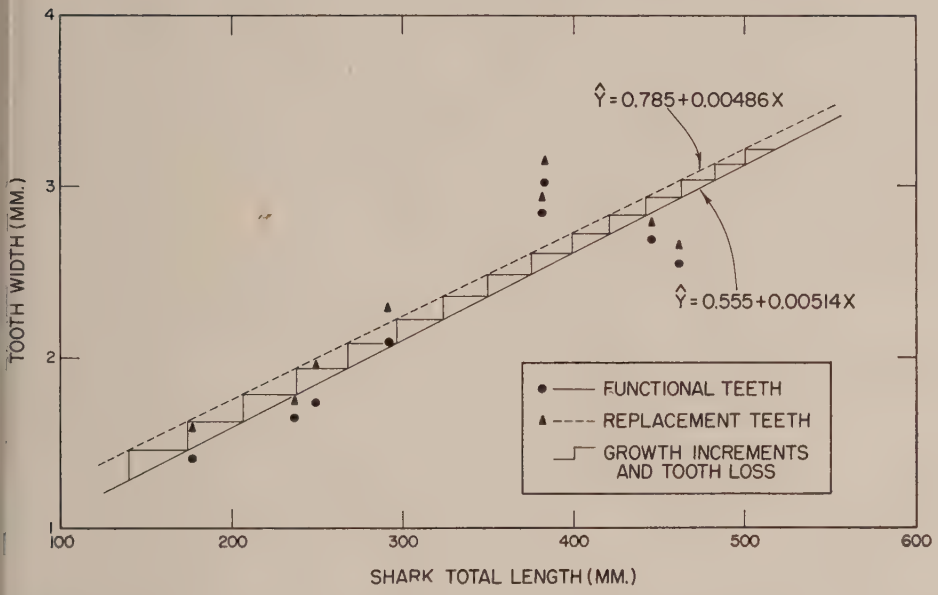


Fig. 4. Tooth width versus total length for *Isistius brasiliensis*. Tooth width is greatest width of mesial mandibular tooth. Regressions calculated by method of least squares.

would further free the individual teeth from each other.

The fact that three of eight stomachs contained teeth indicates that replacement is frequent. An idea of its frequency is given by Figure 4, which shows the relation between functional and replacement tooth widths at various shark lengths. "Tooth width" is the greatest width of the mesial mandibular tooth, while "functional teeth" and "replacement teeth" are the erect and first reversed series, respectively. Exceptions to these definitions were made for the 177-mm shark shown in Figure 3, and the 249-mm specimen whose swallowed teeth are shown in Figure 2. For these animals the displaced teeth were regarded as "functional" and the functional teeth were termed "replacement." The relation between tooth width and shark length was assumed to be linear, and the regressions were calculated by the method of least squares.

The stepwise line between the two regressions of Figure 4 is a diagrammatic representation of the alternate events of tooth-shedding and growth in total length. Each vertical increment represents the nearly instantaneous increase in tooth width when a functional tooth is superseded by its larger replacement. Each horizontal increment shows the shark's increase in length between tooth sheddings. The horizontal and vertical increments would be curves instead of straight lines if the teeth grew while functional, or if the shark increased in length during shedding. Both of these possibilities seem doubtful.

The known length range of *Isistius* is 140–501 mm (Bigelow and Schroeder, 1948: 510–2), and in this interval there are 15 tooth replacements, as shown in Figure 4. In my specimens the number of mandibular teeth ranges from 29–31, and the 15 sheddings thus represent a loss of 435–465 teeth. This is a considerable expenditure of body substance to ensure a fully functioning lower jaw, and one wonders which aspects of *Isistius* biology require such a safeguard. Although the time interval between sheddings is unknown, it is interesting that small *Isistius* grow nearly twice as much between sheddings as do large ones.

Bigelow and Schroeder (1948:511) stated that the mandibular teeth of *Isistius* increase in number as the shark grows. One should be able to verify this hypothesis by comparing the numbers of teeth in the functional and replacement sets. Counts were made of the functional and three re-

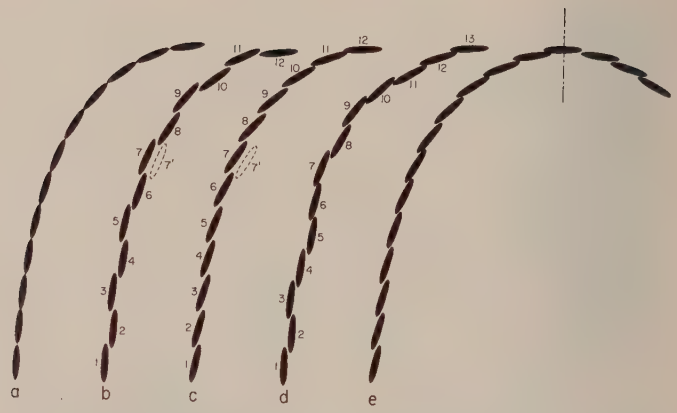


Fig. 5. Tooth arrangements in sharks (diagrammatic). (a) no overlap (independent dentition), (b) alternate overlap, (c) imbricate overlap, (d) mixed alternate and imbricate overlap, (e) modified imbricate overlap as seen in *Isistius*. The dashed outlines represent replacement teeth.

placement dentitions of seven *Isistius*. The number of teeth was constant for all dentitions of a particular shark, discrediting the idea that there is an increase in number with growth. Instead, one would deduce a loss with growth, for the ratios of total length to tooth count in these sharks are: 237/31, 249/31, 292/30, 382/29, 383/29, 446/29, and 462/30. This small sample shows a decline in tooth number with increase in length.

### Tooth Replacement in Other Sharks

The dried jaws of 13 other species of sharks were examined to determine how tooth replacement takes place. The jaw material represents the following species: *Hexanchus griseus* (Bonnaterre), *Isurus glaucus* (Müller and Henle), *Carcharodon carcharias* (Linnaeus), *Alopias pelagicus* Nakamura, *Triaenodon obesus* (Rüppell), *Galeocerdo cuvieri* (LeSueur), *Prionace glauca* (Linnaeus), *Carcharhinus limbatus* (?) (Müller and Henle), *Eulamia floridanus* (Bigelow, Schroeder, and Springer), *Eulamia* sp., *Pterolamiops longimanus* (Poey), *Sphyrna zygaena* (Linnaeus), *Sphyrna lewini* (Griffith), and *Echinorhinus cookei* Pietschmann. Only 21 jaws were available, so most species are represented by a single jaw. All jaws are from adult sharks, 4–11 ft in total length.

A comparison of the number of semi-erect replacement teeth to the number of functional teeth indicates that tooth replacement is quite variable between species. The term "semi-erect" is somewhat subjective, but was applied to all teeth whose position was intermediate between the erect and reversed states. The comparison was made by calculating the percentage of semi-erect to functional teeth; where this value is greater than 100, there is more than one series of semi-erect teeth. In *Echinorhinus cookei* the teeth tend to form a cutting edge, and the single jaw examined has no semi-erect teeth. Many of the other sharks have a moderate number of teeth being replaced at any one time: *Prionace glauca* (14 per cent), *Pterolamiops longimanus* (16 per cent), *Galeocerdo cuvieri* (14 per cent–18 per cent), *Sphyrna zygaena* (19 per cent), *Carcharodon carcharias* (33 per cent), and *Hexanchus griseus* (37 per cent). The semi-erect teeth of *Hexanchus* are restricted to the symphysis and rear parts of the jaws. Some sharks have different replacement rates for the upper and lower jaws, and for these the percentages were calculated separately for each jaw. Examples of this are *Eulamia floridanus* (9 per cent upper jaw, 106 per cent lower jaw), *Eulamia* sp. (11 per cent upper jaw, 96 per cent lower jaw), and one specimen of *Carcharhinus limbatus* (12 per cent upper jaw, 71 per cent lower jaw). Another *C. limbatus* has 44 per cent replacement in the upper jaw and 136 per

cent in the lower, a marked increase over the first specimen. Replacement is further intensified in *Alopias pelagicus* (70 per cent upper jaw, 120 per cent lower jaw), *Triaenodon obesus* (88 per cent upper jaw, 109 per cent lower jaw), *Sphyrna lewini* (86 per cent–88 per cent upper jaw, 125 per cent lower jaw), and *Isurus glaucus* (100 per cent upper jaw, 164 per cent lower jaw). I have been unable to correlate the varying rates of tooth replacement with the observed behavior of these sharks.

The arrangement of the functional teeth shows that replacement is necessarily localized in some sharks. In these, the outward movement of a tooth, caused by the proliferation of dental epithelium (James, 1953), is blocked by other teeth which overlap it. Replacement of the first tooth cannot take place until the blocking tooth is lost. Examples of different kinds of overlap are given in Figure 5, and the reader is also referred to the excellent figures given by Landolt (1947). The simplest arrangement is here called an independent dentition (Fig. 5a). In this, there is no overlap between teeth, and outward movement of any tooth is thus independent of the others. Independent dentitions are found in *Isurus, Carcharodon,* and *Alopias,* while *Hexanchus* and *Echinorhinus* have essentially independent dentitions with a few slightly overlapped teeth. In these sharks there is no mechanical reason for tooth replacement to be a localized phenomenon.

Overlapped teeth are arranged in two ways, termed alternate (Fig. 5b) and imbricate (Fig. 5c) dentitions. No sharks were found with pure alternate or imbricate dentitions, but instead overlapping always involved patches of teeth arranged in both ways. This dual situation is called a mixed dentition and is shown in Figure 5d. It can be seen that teeth 2, 3, 5, 7, 8, 9, and 11 have an alternate arrangement, while teeth 4, 6, 10, and 12 are imbricate. Mixed dentitions are the rule in *Triaenodon, Prionace, Carcharhinus, Eulamia, Pterolamiops,* and *Sphyrna zygaena. Sphyrna lewini* has mostly mixed teeth, with some independent teeth in addition. Of the two available *Galeocerdo* jaws, one has mostly mixed teeth, the other mostly independent. In these sharks the movement of many teeth is blocked, and replacement is thus mechanically localized.

There are several hypothetical ways in which tooth replacement may take place. There is evidence that a mixed dentition is a transitory situation derived from an alternate dentition. In Figure 5b for example, the loss of tooth 7 and its subsequent replacement by 7′, results in teeth 6 and 8 assuming an imbricate rather than an alternate relation to their neighbors. This new arrangement would be termed a mixed dentition. The later loss and replacement of teeth 5 and 9 would restore the alternate arrangement.

A typical mixed dentition cannot be derived from an imbricate dentition. The mandible of *Isistius* (Fig. 5e) comes closest to having an imbricate dentition, and can be used as an example of what might occur. The two halves of the jaw have their teeth imbricated in opposite directions and the mesial tooth is in an alternate position with respect to its neighbors. As has been noted for *Dalatias lichia* (Landolt, 1947), the mesial tooth is obviously in a keystone position, and one would deduce that it must be shed first. With it gone, each successive posterior tooth could be shed. During replacement the area in which shedding was occurring would be marked by a replacement tooth having an alternate, rather than imbricate, position with respect to its neighbors. Tooth 7′ in Figure 5c is an example of this. The mixed dentitions examined did not have a pattern like this, and were thus not derived from imbricate dentitions. The argument is academic in the case of *Isistius,* for it sheds its imbricate dentition as a unit.

The presence of imbricate teeth in mixed dentitions strengthens the hypothesis that only a moderate number of teeth is replaced at one time. If most of the nonblocked teeth (such as 1, 3, 5, 7, etc. in Fig. 5b) were shed and replaced as a unit, then the dentition would be essentially alternate rather than imbricate. In addition, we would occasionally capture sharks with many gaps among their functional teeth. Gaps have been surprisingly rare in the numerous shark jaws seen by me in recent years, and the extensive presence of gaps is also not indicated for the 294 jaws studied by Springer (1960:10). These facts fit Bigelow and Schroeder's hypothesis (1948:65) that for most sharks only a few teeth are replaced at one time.

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Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.

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p. 4-5.

# Chironomids and Trout

By Richard B. Thompson

*(Note: We do not ordinarily print guest articles in the Game Bulletin. However, we felt the following piece would have great appeal to the fly fisherman, and be of some interest to all fishermen. If you haven't tried using the pupa or nymph stages of aquatic insects in your angling, we suggest you do so this season. The author of this article is a past president of the Seattle Chapter of the Washington Fly Fishing Club.—*

Have you ever investigated the contents of the stomach of a freshly-caught trout? Information gained by such a scrutiny is useful in more closely imitating the natural food items on which the trout was last feeding. If you have ever done this, you probably have seen numbers of dark, immature insects about one-half inch in length with a long slender body, an enlarged thorax, and light-colored filamentous gills near the head.

These are the pupae of the emerging adult midges, or Chironomidae. They have been referred to locally as chironomids, midges, chironomidges, and once, called across a lake at dusk by an unknown "entomologist," even as "Geronimo nymphs."

The midges of the Family Chironomidae are delicate, gnat-like flies; the adult males possess conspicuous plumose (feathery) antennae; the head is small, almost obscured by the thorax, with poorly-developed mouth parts, seldom adapted for piercing. In fact, most adult Chironomids do not feed at all.

The majority of fly fishermen have doubtless seen large swarms of these flies and believed them to be mosquitoes, which they resemble very much—only they do not bite. The adults occur in great numbers in the spring and summer in the vicinity of lakes, ponds, streams, and swamps; many appear on the wing just before sunset, and exhibit a characteristic gregarious habit of "dancing" in the air in swarms. Eggs may be deposited singly, in irregular masses, or in strings on the surface, the bottom, or on aquatic plants, depending on the species.

*Fig. 1. Representative Chironomid larvae. 8X*

*Fig. 2. Representative Chironomid pupa. 12X*

The larvae are elongated, cylindrical, slender, and range in length from 2 to 30 millimeters. (Figure 1.) Various species have larvae that are whitish, yellowish, greenish, bluish, pinkish, and some, containing haemoglobin, are bright red and known as "blood worms." The larvae of many species construct fragile tubes composed of algae, silt, or sand grains cemented together with a salivary secretion. These tubes are open at both ends and a current of water is kept passing through by vigorous undulations of the larva's body. Some mud-inhabiting species have developed a filter feeding mechanism. The larva spins a concave net of salivary secretion across the opening, straining plankton and detritus from the water passing through the tube. The larva then eats the whole net and its load of food, after which it spins another net. This whole process is completed in several minutes. Midge larvae, because of their burrowing and sessile habits, are seldom taken by trout.

When the insect has completed its larval stage, it goes into a pupa for metamorphosis into an adult. A representative pupa is shown in Figure 2. Various species may go into this stage resting in the old larval tube in the bottom, which may now be provided with an operculum, or door.

When it is ready to change into the adult fly, the pupa rises to the surface of the water and floats there momentarily in a vertical position. After a brief struggle, the adult insect splits the dorsal surface of the pupal case and emerges. A brief drying and hardening period in the air and the adult is off to join the dancing swarm, pick a mate, breed, and shortly thereafter, die.

The time in the midge's life history that is of greatest concern and interest to Washington lake fly-fishermen is during the pupa's rise to the surface. It is during this period that the midge is available to the fish: the bulk of the Chironomids found in the stomaches of trout are still in their tight pupal cases. This would indicate that they were consumed during their ascent to the surface and before the adult had commenced its emergence.

Many of the eastern Washington "evening rises" are caused by hordes of midge pupae rising to the lake's surface. Larvae are usually found in lakes in waters of less than fifteen feet depth, thus explaining why the bulk of fish activity during such a rise is close to shore. During the period of its rise to the surface the pupa is at the mercy of feeding trout for as long as two-and-one-half minutes, including the emergence and drying periods. Even after the adult fly successfully clears the water it is vulnerable to swallows, which are attracted by the flying adults, and which easily pick them up in flight. It is rather a wonder that these insect populations are able to exist at all.

The imitation of the rising pupae, then, is the objective of the fly fisherman while a "hatch" and a "rise" are going on. The actual imitation, or suggestion, of the pupa itself is quite simple. Various patterns have been developed that are particularly successful. The body of these is usually dark, being constructed of moosemane, wing quills, chenille, fur dubbing or similar materials. Where ribbing is not produced by the body material itself, four or five turns of ribbing should be added. The thorax of the fly should be larger than, or as large as, the diameter of the body; this, too, should be formed of dark, fuzzy material. To imitate or suggest the filamentous gills which are attached to the sides of the head of the pupa, light-colored material can be wrapped as a collar just in back of the head of the fly.

One of the simplest to tie and also one of the most effective nymph patterns in the imitation or suggestion of Chironomid pupae is one known as the TDC. The body of this nymph is built up in a taper with tying thread. This is overwrapped with small black chenille. Four or five turns of narrow silver tinsel ribbing are added. The collar is made of three turns of white ostrich herl and the head is finished with black thread. As simple as that! This, on a size 10 hook, has worked well on Jameson Lake, particularly the south end, Blythe, Sands, and during the winter on Morgan and Halfmoon Lakes.
trout is a creature of impulse . . . he takes."

*Fig. 3. Adult Chironomid yy. 2X*

*Fig. 4. "TDC". The imitation.*

Support for this "soft-outline" approach to nymph imitation or suggestion is found in an article by Ted Trueblood in the May, 1954, issue of True Magazine. He wrote, ". . . However, their (trout) ability to recognize form is not so great. So a trout has been feeding on (midge pupae) and sees the fuzzy, soft-outline imitation in the water. It is the right shade of color. It is approximately the right size and form. But both are impossible to determine accurately because of the fuzzy outline. As to detail, the imitation has none. A trout which could easily see defects in an attempted "exact imitation" nymph, cannot see them here because there is not detail. In the absence of anything to create suspicion . . . and since a trout is a creature of impulse . . . he takes."

In fishing a midge pupae imitation, one can use either a sinking line or a floating line. Since the pupae are rising from the bottom to the surface, they occur at times in all strata and are probably being taken by the trout at all levels, although those near the surface are more evident and usually demand immediate attention from the fisherman. A floating line with a "damp" leader would keep the nymph imitation within one or two feet of the surface, where a good portion of the trout-feeding activity apparently occurs.

At times it seems that a "dead float" or a "dead sink" is most effective. At others a slow, smooth stripping-in of the line seems to be better in inducing trout to take the artificial. Anyhow, fishing is experimenting with different techniques. If you knew the secret of getting a fish on every cast, it wouldn't be nearly as much fun!!

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# 14.

# Sonic Fish Tracking

By

PARKER S. TREFETHEN*

The need for knowledge by fishery agencies of h movements has long been recognized and many chniques, such as disc tags, streamer tags, dyes, and ttoos, have been devised to obtain this important formation. Valuable data have been accumulated y these methods for population studies, catch raluation, timing of migrations, and delays during igration, but none of these tags are able to produce inute-by-minute information on fish movements in ecific areas or on the behavior and orientation of sh in response to specific stimuli in their natural nvironment. Detailed information on behavior of sh is necessary for understanding migrations and redicting changes in migratory routes, for providing dequate fish passage facilities for certain species of sh, and in the management of a fishery.

In the absence of a suitable tag for observing etailed movement patterns of fish, the Bureau of ommercial Fisheries undertook a programme to evelop special equipment that could be employed o observe adult salmon as they migrated upstream. )r. Gerald Collins initiated this research and investiated the possibility of utilizing mechanical noiseakers or radio transmitters attached to a fish, but ese techniques were unsatisfactory and it became pparent that underwater sound was the only feaible method that could be employed.

The Seattle Development Laboratory of Minneaolis-Honeywell Regulator Company under contract o the Bureau designed a sonic tag and produced eceiving equipment that would "home" automatially on the tag's signal and track the fish to which the ag was attached. The first usable tag was an aluminum apsule 0.86 inches in diameter and 2.37 inches ong, and weighed from 0 to 2 grams in water. This as a self-contained battery-operated unit that roduced a pulsed 132 kc signal detectable for eight ours, and had a tracking range of 250 feet.

This tag was employed for three years to observe sh behavior, but after its initial use it became obious that the life and tracking range of this tag was oo short and its operation too unreliable for prolonged xperiments. During this three-year period, however, he advances in sonic and electronic engineering and n subminiaturization of electronic parts made it ossible to design and produce a tag with more esirable characteristics.

The basic tag now in use was designed for us by Automated Controls Company, Alderwood Manor, Washington. It is capable of producing a tracking signal for 24 to 60 hours in fresh water at a range of 500 to 1200 feet; in salt water the range is reduced to about one-third. The dimensions have been decreased to 1.8 inches long and 0.6 inches in diameter, while the weight has been increased by only 6 grams. The frequency of the signal, 132 kc, and the pattern of the signal from the tag are similar to those of the tag previously employed.

The new tag is constructed in two units: (1) the transducer-oscillator unit which contains the resonating zirconium-titanate crystal, printed circuits and necessary electronic components to stabilize the signal in varying temperatures; and (2) the battery unit which contains the power supply. By using different types of miniature batteries and by varying the number of cells in a battery unit the duration of signal can be controlled without altering the dimensions. By increasing the length of the battery unit and utilizing a longer battery, the duration can be increased to over 5 days and the range to over 1500 feet.

The components of each unit are assembled to fit within buterate-plastic shells that, when joined, form a completed tag. This tag is waterproof and capable of withstanding water pressures at depths of more than 100 feet. Attachment to a fish is made with a hog-ring device that is cemented to the tag and clamped into the fish behind its dorsal fin.

This tag has been successfully employed to track fish in salt and fresh water, in shallow water and deep forebays of dams and in rapidly flowing water that is not extremely turbulent. We have found that adult migrant salmon appear to prefer water less than 30 feet deep, that they tend to follow a shoreline and that there is a difference in their behavior between daylight and darkness. Fish have been tracked up to 15 hours, but the duration was usually limited by personnel endurance rather than by the equipment.

We have demonstrated that individual fish can be kept under constant observation in their natural environment with specialized sonic equipment. To accomplish this, it was necessary to employ a tag that is larger than tags used in the usual tagging programmes. Because of its size, and the method of application, its effect on natural behavior patterns is an important consideration in the analysis of the

* Bureau of Com. Fish., Seattle, Wash., U.S.A.

results. We have attempted to minimize the effect of handling while attaching the tag, by keeping the fish under water at all times. About one out of four fish tagged in this manner reacted to the procedure by swimming rapidly around a tagging box for several seconds; the others showed no visible reaction. The fish was then held up to four hours to eliminate the effect of the tagging.

The sonic properties apparently do not affect the behavior of adult migrant fish. Tagged and untagged chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*), tagged with a sonic tag and placed in fast flowing and in quiet water, exhibited no visible differences in their behavior patterns. Several investigators have concluded that fish, when subjected to frequencies between 0.005 and 70 kc, became quickly adjusted to the new sound after an initial "start" and accepted it as part of the large volume of noise normally encountered in their environment.

Another factor that might have affected the validity of the information being collected was the weight of the tag and its drag as it was carried through the water. In so far as possible we streamlined the tag to reduce the drag, but it remained relatively large and the weight was foreign to a fish. A series of tests, designed to compare the movement of tagged and untagged fish through different water conditions in a fisheries behavior laboratory, were conducted to examine the effect of the tag being employed and, also, the effect of a smaller tag that weighed 12 to 15 grams. No effect was observed between tagged and untagged fall-run chinook salmon and blueback salmon of the Columbia River. An apparent effect was observed on spring-run chinook salmon, but we are not certain that the observed behavior is the result of the sonic tag and handling, for in other types of experiments the behavior of spring chinook salmon appears very erratic. More experiments are necessary before we can assume that the tag does not affect behavior of spring chinooks.

Throughout our behavior experiments we have utilized receiving equipment that has been only slightly modified from the original design. This automatic tracking system is servo-powered, utilizing four receiving or detecting barium titanate transducers and four receiver channels for tracking a tagged fish. Two of the transducers are used for tracking in azimuth and two are for tracking in elevation. A 132 kc sound source (sonic tag) in the common axis of a pair of transducers produces a signal in each transducer. As it is moved from the common axis toward the axis of either transducer the output from one rapidly increases toward a maximum, while the output of the opposite transducer decreases. The two signals are used to balance each other in a difference amplifier and the sharply defined null provides sensitivity to vertical and horizontal angular displacement from the common axis. These detecting transducers are clustered around the echo-ranging transducer and when the tag is in the null, or common axis, the ranging system is aimed at the tagged fish. The exact position of the fish is determined by echoes from sound impulses emitted by the ranging unit. These echoes are transformed into electrical energy and displayed on a calibrated cathode-ray tube that shows distance and direction; the depth of the fish can be calculated.

The four receivers, each of which is connected to one of the four detecting transducers, use a t-r-f-circuit with a band pass of $\pm$ 1 kc. For accurate and dependable operation a delicate balance between the receivers must be maintained and a signal level of 5 microvolts is required at the receiver grids.

In view of electronic developments since the original design of the tracking system, our equipment is obsolete and improvements must be made to increase the dependability and accuracy of our observations on fish behavior. In a new tracking system, a single channel would replace the four-channel receiver to eliminate the delicate balance necessary between channels for accurate tracking. A front-end switching unit would separate azimuth and elevation signals received from a sonic tag and activate an improved servo-system to aim echo-ranging equipment at a tagged fish. A high-gain circuit would be employed but the bandpass would be decreased to about 500 cycles or less. This would effectively increase the range of our present tag by eliminating some of the signals or noise now received with the 1 kc band pass. A reduction in noise will also increase the duration that the tag signal can be detected.

New equipment will include a tunable receiver capable of detecting signals over a wide range of frequencies. This will allow us to select a tag frequency most suitable to the water condition, and minimize signal attenuation in turbulent water and in a marine environment. This type of receiver will eliminate the precise adjustment of tag signal that is now necessary before use and enable us to continue tracking a tagged fish regardless of any frequency shift that might be caused by temperature or pressure changes. The ability to utilize lower frequencies will enable us to reduce the size of the sonic tag by nearly one-half, while maintaining the present characteristics. Also, it is conceivable that several tags of different frequencies could be employed at the same time, so that more than one fish could be tracked in a specific area.

We have emphasized the development of automatic tracking equipment in anticipation of long-term fish behavior studies when fish might be tracked

for days or weeks. It is possible, however, to develop a simpler system that could be mechanically positioned by aurally differentiating signal strength; thus, with two or more systems fish could be tracked by triangulation. However, this type of equipment would probably be limited to specific areas from stationary observation points.

The ability to utilize sonic equipment to observe in detail the behavior of individual adult salmon has been adequately demonstrated. Although we will continue to use the present tracking system to accumulate data on salmon behavior, efforts are being directed toward the design and production of new equipment to realize fully the potential of this research tool. A new tracking system design will be based on our experiences coupled with the latest advances in sonic and electronic engineering. The increased accuracy, reliability, and sensitivity will enable us to consider the use of this tool in a marine environment for extensive observations on salmon and other species of fish, some shellfish and marine mammals.

In our development programme we have accumulated considerable experience in the use of sonic equipment in small boats. We gladly offer our assistance in the installation and operation of equipment, the interpretation of data or in tagging-tracking operations. We are hopeful that other fishery agencies will utilize this research tool and contribute basic as well as practical information on behavior patterns of aquatic animals.

**Summary**

An early sonic tag used for 3 years has been replaced by an improved device. A new plastic tag now in use is 0.6 inch in diameter, 1.8 inches long, and weighs 4—6 grams in water. A continuous 132 kc signal can be traced at a distance of 500 to 1200 feet for 24—60 hours. The range can be increased to over 1500 feet for more than 5 days by increasing the length of the tag.

The tag is constructed in two sections: (1) the transducer oscillator unit and (2) the battery unit. It withstands water pressure at depths of over 100 feet. Fall-run chinook salmon (*Oncorhynchus tshawytsha*) and blueback salmon (*O. nerka*) are not affected by the sonic or physical properties of the tag.

Schmidt & Klaunig, Kiel

# 11.

# Marking Fingerling Salmon with Trace-Elements and Non-Radioactive Isotopes

By

P. S. TREFETHEN and A. J. NOVOTNY*

The Bureau of Commercial Fisheries at its Seattle Laboratory** is conducting experiments to develop a permanent mark that can be applied to fingerling salmon quickly, easily and economically, and that can be employed to mark the entire production of a hatchery or specific spawning area. The evaluation of hatchery or spawning area contribution to a fishery has depended upon the recovery of fish marked by clipping one or more fins. While fin-clipping has produced some data for evaluation, the method is time-consuming, expensive, requires the handling of each fish, and usually results in only a portion of the output being marked.

The use of trace elements or non-radioactive stable isotopes would eliminate the disadvantages of fin-clipping and would enable biologists to mark entire productions for identification.

The specifications of a perfect mark might be defined as follows:

(1) Not injurious to the fish.
(2) Has no effect on usual behavior patterns.
(3) Has no harmful effect on metabolism.
(4) Can be applied without handling the fish.
(5) Easily and readily applied.
(6) Can be applied to large numbers quickly and easily.
(7) Readily distinguishable to observers.
(8) Marked and unmarked population differences indistinguishable by predators.
(9) Inexpensive to apply.

With the exception of not being externally visible and easily distinguishable to observers, trace elements and non-radioactive stable isotopes appear to be a perfect mark.

Experiments by biologists have indicated that certain mineral salts can be assimilated into the bone matrix of most vertebrates during juvenile development with no harmful effect. These salts crystallize and remain with the organism in detectable amounts throughout its life cycle with little ion exchange. During their early life history in a freshwater environment, Pacific salmon assimilate certain elements necessary for sustained health and vigor. The radioisotopes of these elements are being used in some countries for permanently marking juvenile fish, and it appears reasonable to believe that contiguous non-radioactive (or stable) isotopes and certain trace elements could be used as a permanent mark for salmon fingerlings.

The present study is still in the primary phases, being only some five months old. Experiments are in progress to determine practical elements and isotopes that can be used in a marking program.

The first part has been the cation toxicity studies. We have one good guide on this. Shaw and Grushkin (1957) clearly demonstrated that the cation toxicity to aquatic organisms is directly correlated to the insolubility of the sulfide of the cation. We have checked this with sockeye salmon, and thus far the correlation holds true. Toxicity studies are still being continued. This phase is important for the study of cation metabolism in ionic solutions, since it determines lethal and permissible concentrations. If certain cations are toxic at low concentrations in solution, we then place emphasis on a dietary introduction study.

The actual determination of the retention of a cation can best be done (in most cases) by using the radioactive isotope of that cation in controlled closed system laboratory studies. Accurate information as to the most successful method of introduction can best be obtained in this manner also.

Once a cation has been demonstrated to be a bone-seeking retentive element, the next phase involves a study of introducing the non-radioactive isotopes. They will be introduced to test lots of fish by addition to their diet or by ionic solution. In the latter method, the fish are placed in a solution of the trace element for 24 to 48 hours. Chinook salmon (*Oncorhynchus tshawytscha*), blueback salmon (*O. nerka*) and rainbow trout (*Salmo gairdneri*) are being subjected to the medium. The chinook and blueback salmon will be released at their normal migration period. It will be necessary to hold fish (such as the rainbow trout) after the last introduction, and sample periodically until vestigial detection has been reached.

The marked fish will be identified by different procedures. Samples of the osseous tissue will be taken and reduced to an ash. The trace elements will be identified by either colorimetric analysis or neutron activation of the ash. The method chosen will depend on its sensitivity for a particular trace element.

Utilizing colorimetric analysis as a technique, one trace element mark would suffice for this, since a

* Bur. of Com. Fish., Seattle, Wash., U.S.A.

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structive analysis of the bone must be made. eutron-activation analysis can be done on a non-structive basis, and many trace elements can be tected in one sample by regulating activation time d reactor flux.

Fortunately, the most promising trace elements are e lanthanide series, and they are detectable by utron-activation to quantities as low as $5 \times 10^{-13}$gm. Durbin et al. (1956) have demonstrated that the erage biological halflife of the entire lanthanide ies in bone is 2.5 years.

In the case of the stable isotopes, only those which n be detected by neutron-activation will be employed. he availability of enriched stable isotopes which n be produced cheaply is currently a problem nich may not be resolved until the demands from dustry become greater.

In practice, the elements or isotopes used would ot be naturally available in either the freshwater marine environment, and would thus be a product the original introductory site when detected in a h. Samples can be taken at any time during the e history and the analysis of osseous tissues will veal their true origin. There appear to be sufficient trace elements and stable isotopes to initiate marking programs through a regulatory agency such as is being done now in the fin-clipping program.

## Summary

The assimilation of certain trace elements and non-radioactive (or stable) isotopes into the osseous tissues of fingerling salmon is the basis of research now in progress. Elements have been selected which are not naturally available in the fishes' environment. They are introduced to the fish in their diet and through the water in their holding tanks.

Toxicity of the substances is being studied. Samples of osseous tissue will be taken and reduced to an ash. The trace elements and stable isotopes will be identified by colorimetric analysis or neutron activation.

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Bacterial Necrosis of Bivalve Larvae.

HASKELL S. TUBIASH* and PAUL E. CHANLEY, Biological Laboratory, Bureau of Commercial Fisheries, U.S. Fish & Wildlife Service, Milford, Connecticut.

Advances in methods for induced spawning of bivalve mollusks and for algal food production have established the feasibility of artificial culture of commercially valuable shellfish species. Paralleling experiences in the husbandry of higher animals, pilot-plant shellfish hatcheries are hindered by a disturbing incidence of highly fatal epizootics in pre- and post-setting nursery stock. A group of gram-negative marine bacterial isolates have been shown to duplicate spontaneously occurring infections. Infection and death with necrosis proceeds rapidly, spreading from foci which demonstrate a characteristic "swarming" by the infecting bacteria. Isolates from hard clam (Mercenaria mercenaria) and American oyster (Crassostrea virginica) larvae and spat are equally infectious for larvae of homologous and heterologous hosts, including the European oyster (Ostrea edulis) and the bay scallop (Pecten irradians). Pathogens have been classified into four serological types by the use of rabbit antisera prepared from isolates of laboratory and field origin. Experimentally induced epizootics have been controlled by prophylactic and therapeutic use of dihydrostreptomycin and chloramphenicol.

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# SYNOPSIS OF BIOLOGICAL DATA ON FRIGATE MACKEREL
# Auxis thazard (Lacépède) 1802 (PACIFIC OCEAN)

Exposé synoptique sur la biologie de l'auxide
Auxis thazard (Lacépède) 1802 (Océan Pacifique)

Sinopsis sobre la biología de la melva
Auxis thazard (Lacépède 1802 (Océano Pacífico)

Prepared by
RICHARD N. UCHIDA
U.S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

FISHERIES DIVISION, BIOLOGY BRANCH
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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* Since no information was available to the author, these items are not listed in the text.

# 1 IDENTITY

## 1.1 Taxonomy

### 1.1.1 Definition (After Schultz, 1960)

Phylum Chordata
Subphylum Craniata
Superclass Gnathostomata
Class Osteichthys
Subclass Teleostomi
Superorder Teleosteica
Order Percomorphida
Suborder Scombrina
Family Scombridae
Genus Auxis Cuvier and Valenciennes 1831
Species Auxis thazard (Lacépède) 1802

The establishment of the genus Auxis under "Les Scombres" first appeared in Cuvier's Règne Animal in 1829. Kishinouye (1915) hailed this work and stated that this marked a great advance in taxonomy. However, from the time of Cuvier's work to the present, the genus Auxis has had several reclassifications. Even the species included under this genus have been confused, with the result that today several names exist for the two or three (?) types of Auxis in the Pacific.

In classifying the genus Auxis, Kishinouye (1915) first included it in the family Thunnidae. However, in a later work (1917a), he created a new order of the Teleostomi and called it Plecostei. He placed the families Scombridae and Cybiidae in the order Teleostei and the families Thunnidae and Katsuwonidae under his new order Plecostei. He placed the genus Thunnus under Thunnidae and the genera Katsuwonus, Euthynnus, and Auxis under the family Katsuwonidae (Kishinouye, 1923). The order Plecostei was established solely on the basis of a partial variation in the vascular system. The primary characteristic of the new order was then the presence of well-developed subcutaneous blood vessels and the secondary characteristic was the development of dark red lateral tissue in relation to the subcutaneous blood vessels. Another difference pointed out was the difference in the kidneys and the vascular systems within the kidneys.

Takahashi (1924) refuted Kishinouye's belief in the need to create a new order and presented his argument. In brief, he stated that the new order Plecostei, which is established solely on the basis of a partial variation in the highly variable vascular system, and only in minor details of that system, cannot exist in an equal status with the other four orders of the Teleostomi and should, therefore, be thrown out.

Another argument against the use of Kishinouye's classification was given by Hildebrand (1946). He stated that difficult dissections are involved in following Kishinouye's classification, and some of the characters are scarcely usable except by an expert.

Wade (1951) pointed out that Herre (1953) and Jordan (1923) placed the so-called scombroid fishes in two families, the Scombridae and Thunnidae. Berg (1947) in his classification created an additional family, which he called Cybiidae. Fraser-Brunner (1950), on the other hand, rejected any division of the family Scombridae, saying that attempts to subdivide the family on the basis of lesser characters have "resulted in arrangements which are artificial and have left the classification in an uneasy shifting state."

Thus, the placement of the genus Auxis depends on the taxonomic authority one wishes to accept.

### 1.1.2 Description

- Genus Auxis Cuvier and Valenciennes 1831

"Body oblong, plump, mostly naked posteriorly, anteriorly covered with small scales, those of the pectoral region enlarged, forming a corselet; snout very short, conical, scarcely compressed; mouth rather small, the jaws equal; teeth very small, mostly in a single series, on the jaws only; tail very slender, depressed, with a rather large keel on each side; first dorsal short, separated from the second by a considerable interspace; second dorsal and anal small, each with 7 or 8 finlets; pectorals and ventrals small; no air bladder; branchiostegals 7; pyloric coeca dendritical; gill rakers very long and slender, numerous; vertebrae 39 in number, peculiarly modified, essentially as in Gymnosarda." (Jordan and Evermann, 1905).

About the genus Auxis, Kishinouye (1915) wrote that this group is more degenerate than Euthynnus, and accordingly differs widely from the other thunnids. The haemal spines of the thoracic vertebrae do not form a haemal arch,

the first vertebra is not fused to the cranium, and the first and second dorsals are not continuous. There is no air bladder. It is a small fish about one foot long, with a short snout and coloration roughly the same as that of E. yaito. However, there are no spots below the pectoral fin.

- Auxis thazard (Lacepède) 1802

The following description of A. thazard is quoted from Matsumoto (1960:174) who examined five specimens of this species:

"Dorsal XI, 10-12, 8. Anal 13, 7. Gill rakers 9-10+1+28-31= 39-42. Total length 272-283 mm.

"Body robust, more or less compressed laterally. Snout short, pointed. Mouth moderate; gape to well past anterior edge of pupil. Each jaw with single row of small, weak teeth. Palatines and vomer toothless. Dorsal fins well separated. Dorsal interspace less than half the distance between the origins of the first and second dorsal.

"Vertebrae 20+19= 39, including urostyle. First haemal arch on 8th vertebra; first closed haemal arch and first haemal spine on 21st vertebra. Haemal canal borne away from body of vertebra by pedicles.

"Body naked, except for corselet of scales. Corselet along lateral line extends posteriorly to about two thirds the distance from the origin of first dorsal to the origin of second dorsal. Lateral line only one or two scale-rows wide beneath second dorsal origin. Lateral line more or less undulating, without any pronounced arch.

"Body markings about 16 dark, oblique bars running posterodorsally and overlying bluish background above lateral line. Bars variable in number and often broken into spots. Dark continuous band over top of head and along dorsal margin of body. The band more or less uniform in width to above tip of pectorals whence it narrows posteriorly to base of second dorsal finlet. Body below lateral line silvery white and free of markings or spots." (Fig 1.)

Matsumoto (1959) describes the corselet as "a plaque of scales on the anterior part of the body in the form of three wedges, whose apices point posteriorly. The dorsal wedge begins near the tip of the pectoral fin, halfway between the lateral line and the dorsal edge of the body. The outline trails posteriorly, toward the origin of the second dorsal fin. From the anterior end of the dorsal wedge, the dorsal profile of the middle extension of the corselet trails posteriorly and ventrally toward the lateral line and meets its complement which begins near the angle of the opercle and rises obliquely toward the lateral line. The lower wedge begins near the angle of the opercle and trails ventrally toward the tip of the ventral fins. Variations in the length of the corselet occur only in the middle branch which roughly follows the lateral line; hence the term corselet as used in this paper shall refer to this middle extension."

On external coloration of the live specimen, Serventy (1941) stated that A. thazard resembles E. alletteratus, commonly called mackerel tuna, in having a wavy mackerel-like pattern on the back. This pattern is, however, somewhat indistinct in A. thazard and instead of being on a dark green background, the markings are laid on a lead-colored one. After death, the fish presents a shiny, lead-like appearance, which somewhat resembles the lead-pencil shading on note paper and to which the name "leadenall" is due.

The color of a specimen preserved in alcohol was noted to be blackish-blue above, lighter below, and becoming silvery on the belly. The color of the fins was the same as the adjacent body color (Jordan and Evermann, 1905).

1.2 Nomenclature

1.2.1 Valid scientific name

- Auxis thazard (Lacépède) 1802

There is much confusion at present among taxonomists and hence in the literature as to the number of valid species of this genus. Evidently, there are some who believe that there is only one single world-wide species and this is A. thazard. There are others who just as firmly believe that one or more additional species are to be found.

1.2.2 Synonyms

In the Pacific Ocean, the scientific names which are ascribed to A. thazard or some of the other closely related species are given below (De Beaufort and Chapman, 1951; Rosa, 1950).

| | |
|---|---|
| Scomber thazard | Lacépède, 1802 |
| Auxis taso | Cuvier and Valenciennes, 1831 |
| Auxis thynnoides | Bleeker, 1855 |
| Auxis rochei | Günther, 1860; Steindachner, 1868; Mellis, 1875; Jordan and Gilbert, 1882; Goode, 1880; Steindachner and Doderlein, 1885; Kitahara, 1897; Hoek, 1914; Borja, 1920; Travis, 1925; Jenkins, 1925; Jordan, Evermann, and Clark, 1930; Irvine, 1947 |
| Auxis hira | Kishinouye, 1915; Jordan and Hubbs, 1925; Soldatov and Lindberg, 1930 |
| Auxis maru | Kishinouye, 1915; Soldatov and Lindberg, 1930 |
| Auxis tapeinosoma | Bleeker, 1854; Verhand, 1846; Günther, 1860; Wade, 1949 |

In a paper presented for discussion at the Pacific Tuna Biology Conference in Honolulu, Hawaii, in August 1961, Roedel and Fitch reported on the taxonomy and nomenclature of the Pacific tunas. It would be appropriate at this time to quote what these authors had to say about the genus Auxis. They stated (p. 12), "We mention these fishes only because they fit in the group as we have defined it. For some years we have been working on genus Auxis as an off-time avocation. Any comment, other than to mention that this genus is as muddled as any we have discussed, would be premature."

Some of the works of other investigators are summarized here to illustrate the present confused state of the genus Auxis.

An account from the work by Wade (1949:230) on the Philippine frigate mackerels states, "A survey of the available literature shows that possibly two seemingly similar species occur in the eastern Pacific area. Comparison of two descriptions of specimens of this genus (Meek and Hildebrand 1923; and Fowler 1938) reveals that the authors were describing two entirely different species. Fowler's description based on two specimens from the Galapagos Islands off the west coast of South America agrees with Auxis tapeinosoma as defined here, having the elongate posterior prolongation of the corselet along the lateral line and the increased gill-raker count. The description by Meek and Hildebrand based upon a composite collection of six specimens from Woods Hole, Mass., Hawaii, and Java agrees in gill-raker count of the lower gill arch with Auxis thazard as named here. The specimen used by Walford (1937) to illustrate Auxis thazard is clearly identifiable as A. tapeinosoma with its long posterior extension of the corselet along the lateral line. It is not known whether the eastern Pacific forms are identical with the species occurring in Philippine waters, and a careful study of a considerable number of collections will be necessary before this can be ascertained."

Kishinouye (1915) stated that there are two species in Japanese waters which are distinguished by differences in the number of scales on the lateral line and in the breadth of the body. In the species he consequently named A. hira, he noted that posterior to the end of the corselet there are only one or two rows of scales above and below the lateral line, while in the species he named A. maru the median portion of the corselet becomes very narrow and ends posterior to the anal fin. He further stated that A. maru is probably the same species as A. thazard of the South Seas, however, it is not known whether thazard corresponds to A. hira or to A. maru. He concluded that Bleeker's A. tapeinosoma may also be this species, but the figure and description of this species were very rough and unclear. This compelled Kishinouye to give these fishes the new specific names of hira and maru.

A partial description of the external features of A. hira and A. maru is given.

Auxis hira Kishinouye

"D. 10-11, 12, 8. A. 13, 7. Gill rakers 9+30.

"Body more or less compressed, its height is nearly equal to the length of the head. Middle limb of the corselet ends a little behind the pectoral, and one or two rows of minute scales are found on either side of the lateral line." (Kishinouye, 1923)

Auxis maru Kishinouye

"D. 9-10, 11-12, 8. A. 13, 7. Gill rakers 10+36.

"Body fusiform, nearly rounded in cross-section, and its height is smaller than the length of the head. The middle limb of the

corselet is prolonged backward nearly the entire length of the lateral line." (Kishinouye, 1923)

In a discussion of A. hira and A. maru of Kishinouye, Wade (1949) pointed out that the description of the larger of the two Japanese species, A. hira, agrees quite well with the description of the Philippine A. thazard, while the description of the second, smaller species, A. maru, seems identical with the species provisionally called A. tapeinosoma by Dr. Herre, formerly ichthyologist of the Philippine Fishery Program. On this basis, Wade provisionally placed A. hira in synonymy with A. thazard, and A. maru in synonymy with A. tapeinosoma.

Fraser-Brunner (1950), on the other hand, believes that A. hira is a synonym for A. tapeinosoma. He states, "Specimens from Celebes, Amboina, and Japan have a slightly longer postorbital part of the head; they represent a local subspecies (tapeinosoma, of which A. hira is a synonym). I can find no difference between specimens from the Atlantic or Melbourne, Australia, representing the typical subspecies, which also reaches Japan (A. maru = A. thazard)." Thus, Fraser-Brunner indicates that he is in agreement with Kishinouye's statement that A. maru is probably the same species as A. thazard.

The FAO Yearbook of Fishery Statistics (1959) lists A. thazard = A. hira and A. tapeinosoma = A. maru.

In 1951, Mead injected some doubt as to whether A. tapeinosoma was really the long-corseletted form of Auxis. In a footnote, he stated, "Wade's description of Auxis tapeinosoma agrees with that of Bleeker (1854). However, the pattern and extent of the corselet scales in Bleeker's figure (1854, pl. 7) of A. tapeinosoma agrees more closely with Wade's figure of A. thazard."

Matsumoto (1959), in the course of his work on identification of tuna and tuna-like larvae, also became involved in the identification of the adult forms of Auxis. In his Dana Report No. 50, he pointed out that there is general acceptance that two forms of Auxis exist and these can be separated from each other mainly by a difference in the corselet development.

Matsumoto stated that A. thazard is characterized by a short corselet which tapers very abruptly at a point just past the tip of the pectoral fin. From this point, the corselet is only one scale-row wide and extends posteriorly only to about midway between the origins of the first and second dorsal fins. In the second form of Auxis, the corselet tapers gradually and extends to and in many instances goes beyond the base of the second dorsal finlet. On Auxis specimens 195 mm to 200 mm in total length, the corselet is 9 to 18 scale rows wide just below the origin of the second dorsal fin.

Further research by Matsumoto showed that the nomenclature of the long-corseletted form is quite confused. He stated (1959) "For many years, the name tapeinosoma Bleeker was ascribed to such specimens taken in the Philippine waters. After studying Bleeker's (1854) description of tapeinosoma, the author has come to the conclusion that this is not the long-corseletted form. Bleeker describes tapeinosoma as having a corselet which 'ends slightly posterior to the pectoral fins.' Most of the other characters he mentions agree more closely with specimens of thazard than they do with specimens of the Philippine long-corseletted form. Furthermore, through correspondence with John E. Fitch, California Department of Fish and Game, who examined the type specimen of tapeinosoma, the author learned that Bleeker's fish is definitely the short-corseletted form. Bleeker's (1855) description of a specimen from Ternate, East Indies, which he named A. thynnoides, seems to be the long-corseletted form. He describes this fish as having a corselet which 'ends far behind the pectoral fin.'"

In 1960 Matsumoto wrote "It is apparent from the original description and from Fitch's information that thynnoides is the earliest available name for the western Pacific long-corseletted species." Thus in his works published in 1959 and 1960, Matsumoto called his long-corseletted form A. thynnoides Bleeker, stating that the long-corseletted tapeinosoma of Wade (1949) and of Herre and Herald (1951) appears to be a misnomer. Matsumoto, therefore, is in agreement with the statement made by Mead (1951).

A. thynnoides Bleeker, shown in Fig. 2, is described by Matsumoto (1960) who based his description on 20 specimens deposited at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.

"Dorsal X - XI, 10-11, 8, Anal 12-13, 7. Gill rakers 10-11+1+32-36=43-48. Total length 262 mm - 290 mm.

Fig. 1 Auxis thazard (Lacépède) (from Matsumoto, 1960)

Fig. 2 Auxis thynnoides Bleeker (from Matsumoto, 1960)

Body robust, fusiform, almost cylindrical in cross section. Snout short, pointed. Mouth moderate; gape to slightly past anterior margin of pupil. Each jaw with single row of small, weak teeth. Palatines and vomer toothless. Dorsal fins well separated. Dorsal interspace slightly greater than half the distance between origins of first and second dorsals.

"Vertebrae 20+19 = 39, including urostyle. First haemal arch on 8th vertebra; first closed haemal arch and first haemal spine on 21st vertebra. Haemal canal borne away from body of vertebra by pedicles [of Starks (1910) epihaemal processes of Kishinouye (1923)].

"Body naked, except for corselet of scales. Corselet along lateral line extends beyond vertical through posterior end of second dorsal. Corselet 16-18 scale-rows wide below origin of second dorsal fin. Lateral line more or less undulating, without any pronounced arch.

"Body markings consist of 14-16 dark, nearly vertical bars over bluish background above lateral line. Bars often broken into spots. Dark continuous band over top of head and along dorsal margin of body. The band more or less uniform in width to end of second dorsal, whence it narrows posteriorly to base of caudal fin. Body below lateral line silvery white and free of markings or spots".

Fig. 3 shows a sketch of the corselet formation found in the two types of Auxis (from Matsumoto, 1959: Figure 18).

In discussing the difference in number of scale-rows between the smaller long-corseletted frigate mackerel of the Philippines and the larger specimens taken in Hawaiian waters, Matsumoto (1960) concluded from an analysis of the regression of number of scale rows on fish length that the number of scale-rows increases as the body length increases (Fig. 4). Thus, the variation in corselet width between the Philippine and Hawaiian specimens represents growth rather than a species difference.

#### 1.2.3 Standard common names, vernacular names

The common names most closely associated with A. thazard in the Pacific are given below. The list was abstracted from the compilation of scientific and common names applied to tunas, mackerels, and spearfishes of the world (Rosa, 1950). The common names for the two species of Auxis in Japanese waters have been divided to associate the proper common names to each. Additional common names as they were encountered in the literature were added to the list compiled by Rosa. The names capitalized are in more general use.

### 1.3 General variability

#### 1.3.1 Subspecific fragmentation (races, varieties, hybrids)

The meristic counts of Auxis thazard as reported by several authors are given in Table I. Table II gives the comparison of meristic counts of A. maru, A. tapeinosoma, and A. thynnoides.

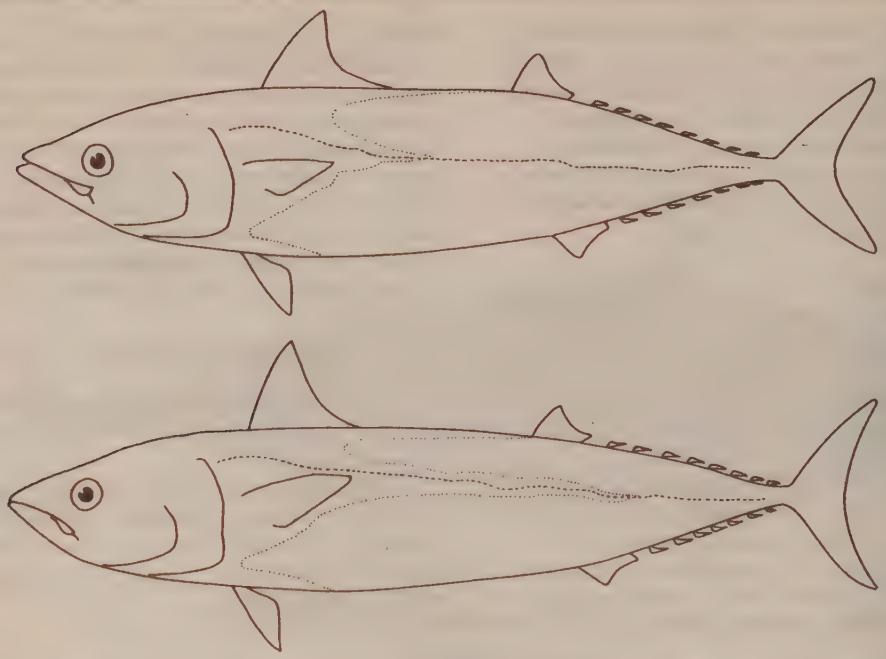

Fig. 3 Sketch of Auxis showing corselet formation (from Matsumoto, 1959)

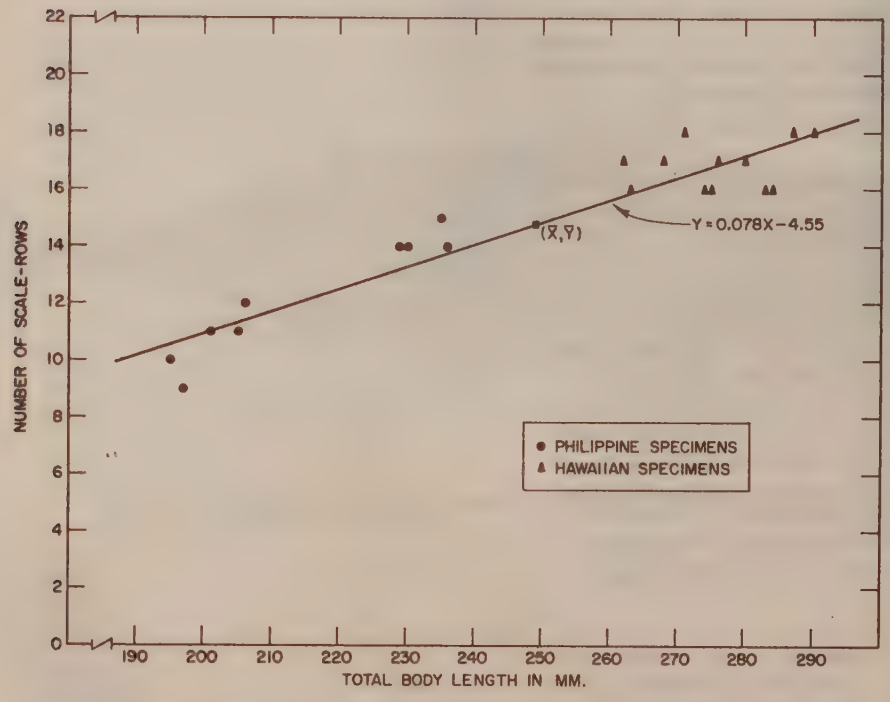


Fig. 4 Regression of the number of scale-rows on total body length of Auxis thynnoides (from Matsumoto, 1960)

| Country | Common names |
|---|---|
| Australia | FRIGATE MACKEREL, Leadenall |
| Canada | FRIGATE MACKEREL |
| Hawaiian Islands | FRIGATE MACKEREL, Keokeo, Mexican skipjack |
| Japan | |
| *Auxis* sp. | SŌDAGATSUWO |
| *A. thazard* = *A. hira* | HIRASŌDA, Hirasōdakatsuo, Hiramejika, Obosogatsuwo, Shibuwa, Soma, Suma, Oboso (Hirasohda, Hiragatsuo, and Hiramedika are variations in spelling of some of the above names) |
| *A. thynnoides* = *A. maru* | MARUSŌDA, Marusōdakatsuo, Marugatsuwo, Marumejika, Magatsuwo, Manba, Mandara, Chiboh, Dainanpo, Nodoguro, Rohsoku, Subota, Uzawa, Mejika, Soku, Soda, Subo (Marumedika, Marugatsuo, Magatsuo and Dainanbo are variations in spelling of some of the above names) Other names mentioned by Rosa (1950) are Kogatsuo, Fukarai, Kobukura |
| Mexico | BONITO |
| New Guinea (Netherlands) | Deho |
| Philippine Islands | FRIGATE MACKEREL, Manko, Mangko (Marinao, Samal, Visayan, and Tao Sug) Note: The Philippine dialects are shown in parentheses |
| United States | FRIGATE MACKEREL |

In respect to the origin of the common name in the United States, Goode in 1884 (p. 306) wrote, "The Frigate Mackerel has been observed in the West Indies, and other parts of the tropical Atlantic, as well as on the coast of Europe. In Great Britain it is called the 'Plain Bonito.' It is not unusual in the Bermudas, where it is called the 'Frigate Mackerel,' a name not inappropriate for adoption in this country, since its general appearance is more like that of the Mackerel than the bonito, while in swiftness and strength it is more like the larger members of this family."

Table I

Comparison of meristic counts of Auxis thazard

| Anatomical features | Hawaii (Jordan and Evermann, 1903) | Japan (Kishinouye, 1923) A. hira | So. Calif. (Barnhart, 1936) | Philippines (Wade, 1949) | Hawaii (Matsumoto 1960) |
|---|---|---|---|---|---|
| First dorsal fin | X | X-XI | X | X-XII | XI |
| Second dorsal fin | 12 | 12 | 12 | 10-12 | 10-12 |
| Dorsal finlets | 8 | 8 | 8 | 8 | 8 |
| Anal fin | 13 | 13 | 13 | II, 8-11 | 13 |
| Anal finlets | 7 | 7 | 7 | 7 | 7 |
| Gill rakers | 30+10 | 9+30 | - | 9-10+1+27-32= 37-43 | 9-10+1+28-31=39-42 |
| Vertebrae | - | 20+19 | - | - | 20+19 |
| Branchiostegals | 7 | - | - | 7 | - |

Table II

Comparison of meristic counts of Auxis maru, A. tapeinosoma, and A. thynnoides

| Anatomical features | A. maru Japan (Kishinouye, 1923) | A. tapeinosoma Philippines (Wade, 1949) | A. thynnoides Hawaii (Matsumoto, 1960) |
|---|---|---|---|
| First dorsal fin | IX-X | X-XI | X-XI |
| Second dorsal fin | 11-12 | 10-12 | 10-11 |
| Dorsal finlets | 8 | 7 | 8 |
| Anal fin | 13 | II, 10-12 | 12-13 |
| Anal finlets | 7 | 7 | 7 |
| Gill rakers | 10+36 | 10-12+1+31-35= 44-48 | 10-11+1+32-36= 43-48 |
| Vertebrae | 20+19 | - | 20+19 |

## 2 DISTRIBUTION

### 2.1 Delimitation of total area of distribution and ecological characterization of this area

In the compilation by Rosa (1950) the geographic distribution of A. thazard is given as follows:

In the North Pacific Ocean; "Coast of the United States as far north as San Pedro on the coast of California, Hawaiian Islands, coast of Mexico around Cape Corrientes, coast of Costa Rica, Panama, Philippines, Formosa Islands, coast of China around Ningpo and southern Manchuria, Ryukyu and Bonin Islands, coast of Japan as far north as Hokkaido in the Pacific Ocean and Sea of Japan, coast of Korea, rather uncommon in U.S.S.R. waters around Vladivostok."

In the South Pacific Ocean, Rosa lists A. thazard as distributed around the coast of the Territory of Papua, New Guinea, and along the eastern coast of Australia as far south as Tasmania.

Kishinouye (1923) states that Auxis has a wide distribution in temperate and tropical waters.

Matsumoto (1960) noted a new distribution record for the long-corseletted A. thynnoides from Hawaiian waters. He stated that 21 of these long-corseletted Auxis were taken from the same school together with five short-corseletted frigate mackerel (A. thazard). The catch was made from the research vessel "John R. Manning" of the Pacific Oceanic Fishery Investigations (POFI)[1/] by pole-and-line fishing, one mile offshore, two miles northwest of Cape Kaea, Lanai, Hawaii. Matsumoto remarked that although the long- and short-corseletted Auxis are known from both sides of the Pacific, only the short-corseletted form has been reported previously from the central Pacific Ocean.

The distribution of Auxis sp. in Philippine waters is given by Wade (1949). He stated "In Philippine waters Dr. Herre (1940) has recorded Auxis thazard from Nasugbu, and Balayan Bay, Batangas Province, Luzon, and in 1931 from Jolo, Sulu Province. Recent records made by biologists of the Philippine Fishery Program include, in addition to the above localities: Maya, Danao, and Cebu City, Cebu Island; Bohol Island; Zamboanga City, Davao, and Margosatubig, Mindanao; and Iloilo City, Panay Island. Previously Auxis tapeinosoma has never been recorded from the Philippines, but during the past year specimens have been collected at Siocon Bay and Zamboanga City, Mindanao, and Batangas Bay, Luzon."

### 2.2 Differential distribution

#### 2.2.1 Areas occupied by eggs, larvae, and other junior stages; annual variations in these patterns and seasonal variations for stages persisting over two or more seasons. Areas occupied by adult stages: seasonal and annual variations of these

Wade (1951) pointed out in his work on the Philippine tuna and tuna-like larvae that the greatest catch of larvae of Auxis sp. was made during the months of January, February, and March. During the remainder of the year, the collection was meager.

Wade also mentioned that small juvenile Auxis begin to appear on the market in late November and are found in increasing numbers until January and February. They decrease in quantity thereafter and are not found after May. The marketed juveniles were taken in both Batangas and Balayan Bays, which are well protected.

Strasburg (1960) reported that the larvae of frigate mackerel were infrequently captured at the surface during the day, but were often taken there in numbers at night. Furthermore, the captures of frigate mackerel larvae were much greater in the 0-60 m plankton tows than in the surface tows.

From studying a large number of recently hatched larvae of Euthynnus and Auxis measuring 3 mm to 4 mm in total length, Matsumoto (1959) hypothesized that localities where larvae of this size occurred represented the actual spawning sites. He deduced that larvae of

1/ Now the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii

about 3 mm like the eggs which precede them, are planktonic and that their displacement from the spawning site was due to ocean currents. Thus with the exception of a few areas where ocean currents are strong, the displacement of tuna larvae from their actual spawning sites is relatively insignificant. Of the Auxis, Matsumoto concluded that the spawning sites may be near land masses, but its spawning sites also include oceanic situations, as indicated by larval captures as much as 900 miles from land in the Pacific Ocean. Part of Matsumoto's (1959) figure 31 (Dana Report No. 50) is shown in Fig. 5 and gives the localities of capture of Auxis larvae by the "Dana" and a research vessel of the Pacific Oceanic Fishery Investigations in the Pacific.

2.3 Behavioristic and ecological determinants of the general limits of distribution and of the variations of these limits and of differential distribution

Okachi (1958) studied the frigate mackerel taken in the Japan Sea. His results indicated that the lower limit of water temperature for occurrence of Auxis may be about 12°C (53.6°F). He found that there is a slight increase in the catch in summer after the water temperature has risen above 20°C (68.0°F), but during the period of southward movement, when peak catches occur, the water temperature has dropped to about 16°-19°C (60.8° to 66.2°F).

According to the table constructed by Kishinouye (1923) showing the water temperature in which scombroid fishes are found, A. hira and A. maru occupy temperatures ranging from about 14° to about 25°C (57.2° to 77.0°F).

## 3 BIONOMICS AND LIFE HISTORY

### 3.1 Reproduction

#### 3.1.1 Sexuality (hermaphroditism, heterosexuality, intersexuality)

The frigate mackerel is heterosexual, as is true with all the other scombroids. However, there are published reports of hermaphroditism occurring among scombroid fishes. Nakamura (1935) recorded and described a hermaphroditic skipjack, while Uchida (1961) reported on two separate instances of hermaphroditism in skipjack taken in Hawaiian waters. Thus, it is not unreasonable to expect hermaphroditism to occur in Auxis.

There are no externally visible reproductive organs which distinguish the male from the female of the species.

In general, the scombroid fishes have reproductive organs that are paired and elongated on the roof of the abdominal cavity. These organs are suspended in a fold of the peritoneum and extend along almost the entire length of the body cavity. The organs on both sides are nearly symmetrical. Kishinouye (1923) states that the reproductive organs of the Auxis, both male and female, extend posteriorly along the side of the anal fin. This posterior extension, he states, is caused by the narrowness of the abdominal cavity.

#### 3.1.2 Maturity (age and size)

Tester and Nakamura (1957) noted that the frigate mackerel taken off Kaneohe Bay, Oahu, Hawaii, which averaged about 1-1/2 pounds in weight, had gonads that were mostly in the maturing stage or nearly mature stage of development. Included in their catch was one male which weighed 2-1/2 pounds with gonads which they classed as being in the "mature" stage of development.

#### 3.1.3 Mating (monogamous, polygamous, promiscuous)

No information is available on the mating habits of the frigate mackerel, but in general it is believed that scombroid fishes release their sexual products directly into the water without pairing of the male and female as such. The mechanism which triggers the reproductive activity, that is spawning and fertilization, is still unknown.

#### 3.1.4 Fertilization (internal, external)

Fertilization is external. It is presently believed that scombroid fishes expel their reproductive elements into the water when mating.

#### 3.1.6 Spawning

- Spawning seasons (beginning, end, peak)

Schaefer and Marr (1948) state that the capture of juveniles indicates that A. thazard spawns in Central American Pacific waters during the early spring.

The earliest record of the spawning habits of the Auxis sp. in the Pacific is given in an account by Kishinouye (1923). He states that the species called A. hira seems to spawn in the summer and that nearly ripe reproductive elements are found in the adults in August.

Of the Auxis occurring in Philippine waters, Wade (1951) concluded that the principal spawning activities occur during the winter and that scattered spawning takes place the remainder of the year.

On spawning of the A. maru, Kishinouye (1915) remarked that this species spawns during the summer months.

Presumably, Auxis also spawn in Hawaiian waters. In his report citing an instance of natural mass mortality of larval frigate mackerel in the Hawaiian Islands, Strasburg (1959: Fig. 4) showed the length frequency distribution of 2,561 specimens. These ranged in size from about 2.2 mm to about 8.3 mm in total length. In section 2.2.1, Matsumoto (1959) hypothesized that localities where larvae of about 3 mm to 4 mm in total length occurred could possibly be the actual spawning site of the adult. Although Strasburg noted that all his specimens were past the critical yolk-sac stage, it argues by Matsumoto's hypothesis that the smaller frigate mackerel larvae perhaps averaging about 3-4 mm are recently hatched fish. Strasburg gives the dates of capture of these larval frigate mackerels as between July 11-13, 1957. Thus, it can be concluded that some spawning occurs during June or July in Hawaiian waters.

Wade (1951) found that in the Philippines the greatest catch of Auxis larvae occurred

Fig. 5 Localities of capture of Auxis larvae in the Pacific Ocean by the "Dana" and POFI vessel (from Matsumoto, 1959)

during the months of January through March. The catch during the rest of the year was very meager. He states that small juvenile Auxis begin to appear on the market in late November and become more abundant until January and February, after which time they begin to decrease in quantity. After May, the juveniles are not found on the market. From the time of occurrence of larvae and juveniles, it may be possible to conclude that spawning occurs during the fall and winter months in Philippine waters.

3.1.7 Spawning grounds

- Oceanic (surface, bottom)

Juveniles of Auxis are taken in fish traps and several types of local nets close to the shore and in open waters of well-sheltered Batangas and Balayan Bays (Wade, 1951). From these findings, Wade concluded that the adults of Auxis spawn in protected, more or less shallow areas, fairly close to land.

In his Dana Report of 1959, Matsumoto discussed the spawning areas of the Euthynnus and Auxis as indicated by larval catches. He pointed out that the genus Euthynnus spawns in the vicinity of land masses judging from the localities in which the adults and larvae were captured, and this may be said also for the Auxis. However, because spawning sites of the Auxis also include oceanic situations, as deduced from larval captures as much as 900 miles from land, the genus Auxis may be considered a more pelagic spawner than the Euthynnus.

3.1.8 Egg: Structure, size, hatching type, parasites and predators

Matsumoto (1958) discussed the observations made by Sanzo (1932, 1933), on the development of the embryo in the eggs of Orcynus thynnus and Orcynus germo. (Matsumoto believes that the former could be the bluefin tuna and the latter could be either yellowfin or albacore.) Undoubtedly, the eggs, after they are expelled and fertilized, remain planktonic and float with the current. Matsumoto deduced from other studies on eggs of pelagic species of fish that the eggs of tunas probably have an incubational period of not more than four days.

3.2 Larval history

3.2.1 Account of embryonic and juvenile life (prelarva, larva, postlarva, juvenile)

According to Matsumoto (1959) the Auxis larvae with which he worked exhibited some variation in pigmentation and since there is a possibility that this variation may be due to the presence of two species of Auxis, he described two separate series of larvae. These were designated as types I and II, and the validity of this separation was discussed in his report.

The descriptions of the type I and type II larvae are quoted from Matsumoto (1959), and his figures, from 19 to 29, are reproduced here in Figs. 6 to 16.

Auxis type I.

"(1) Two or more rows of chromatophores in the region of the caudal peduncle. In this particular series, even the smallest specimen, 4.5 mm (Fig. 6), has 3 distinct rows of close-set chromatophores along the middorsal, midlateral, and midventral lines of the caudal peduncle. The chromatophores increase in number with growth of the fish, and by the time the species has attained 11.2 mm (Fig. 10), 1 or 2 rows of chromatophores are present along the dorsal midline of the body from the origin of the first dorsal fin to the caudal peduncle. The number of chromatophores along the midlateral line also increases, and in a 13.2 mm specimen (Fig. 11) the chromatophores have moved internally toward the vertebral column. At about 14.0 mm a single row of dermal chromatophores is seen along the midlateral line slightly posterior to the tip of the pectoral fin. This row gradually increases in width and length until it appears as a wide, dark band, which is distinctly noticeable in the 25 mm specimen (Fig. 12).

"(2) Pigment spot at the symphysis of the pectoral girdle. This spot, common to both Auxis and Euthynnus, is present in nearly all of the specimens examined. It usually consists of a single large chromatophore in specimens below 20 mm. In larger specimens, however, this spot may be represented by 2 to 4 small, closely grouped chromatophores.

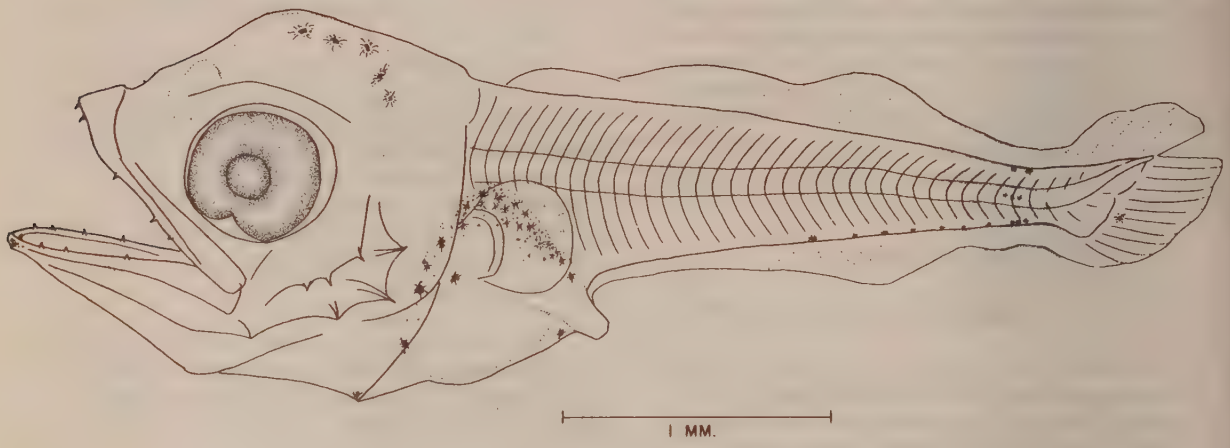


Fig. 6 Auxis type I, 4.5 mm (from Matsumoto, 1959)

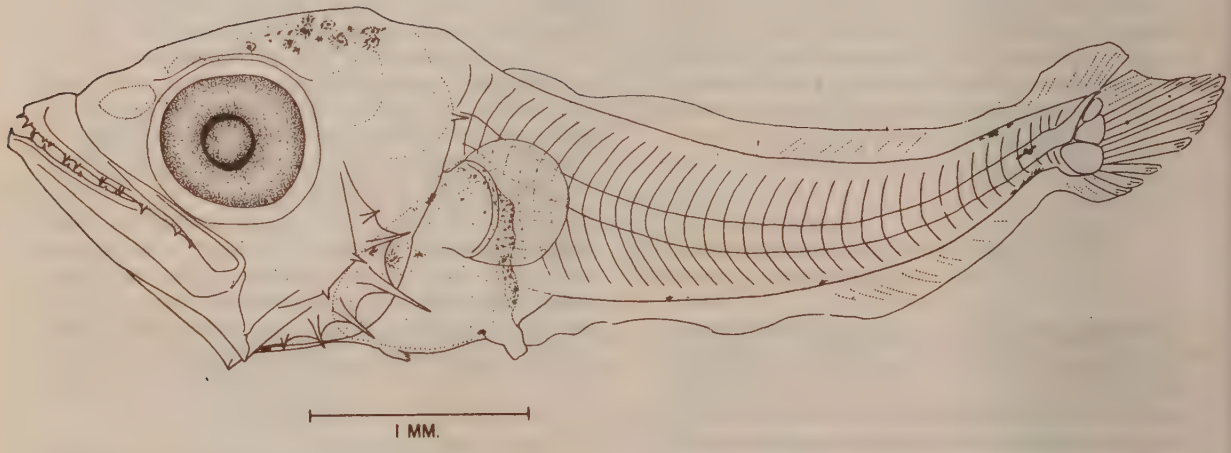


Fig. 7 Auxis type I, 5.5 mm (from Matsumoto, 1959)

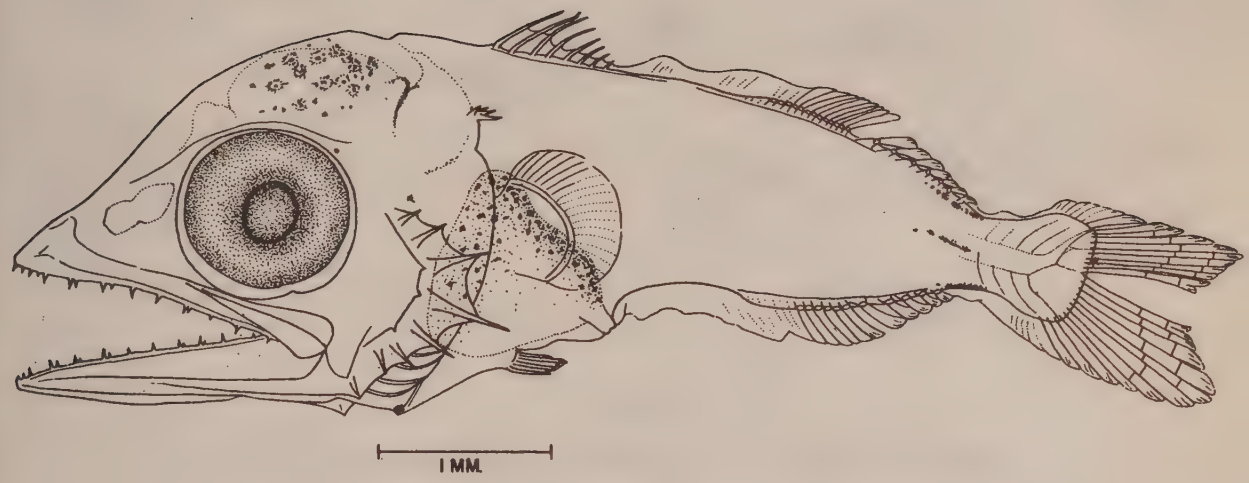


Fig. 8 Auxis type I, 7.05 mm (from Matsumoto, 1959)

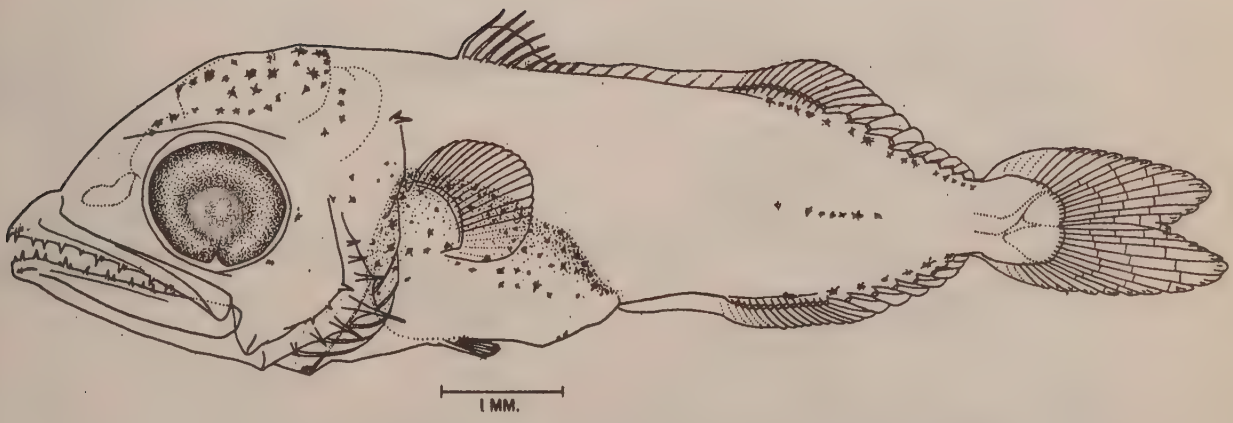


Fig. 9 Auxis type I, 9.7 mm (from Matsumoto, 1959)

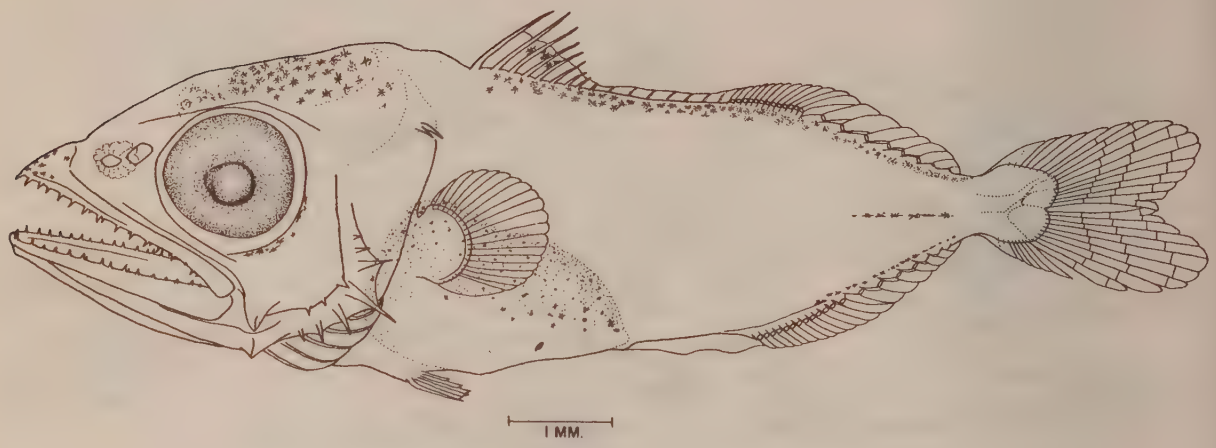


Fig. 10 Auxis type I, 11.2 mm (from Matsumoto, 1959)

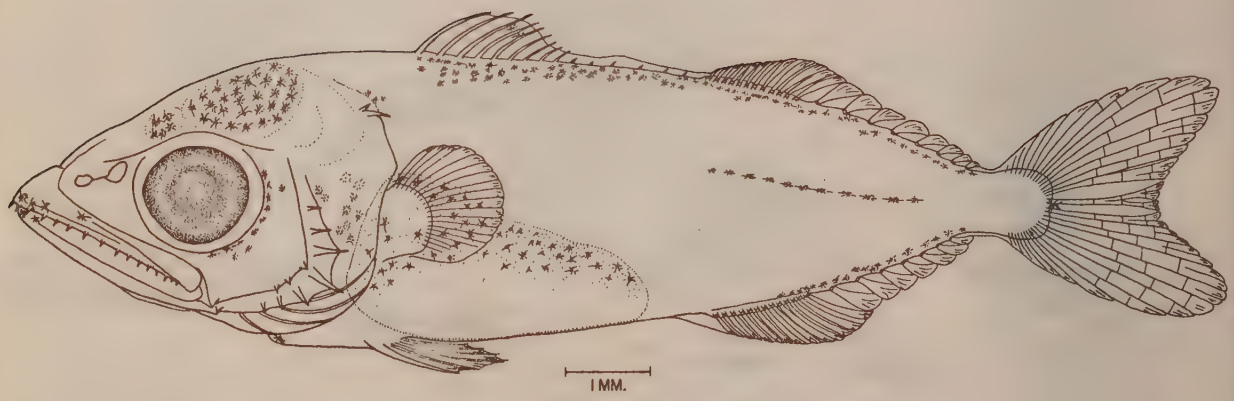


Fig. 11 Auxis type I, 13.2 mm (from Matsumoto, 1959)

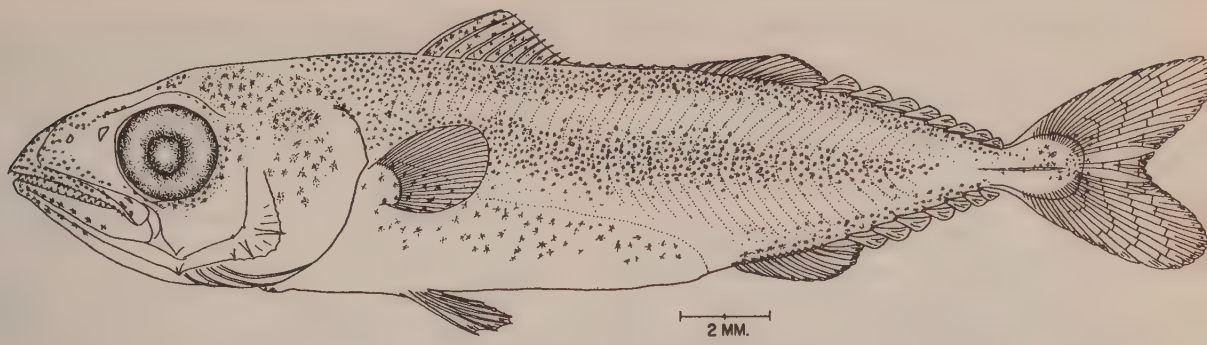


Fig. 12 Auxis type I, 25.0 mm (from Matsumoto, 1959)

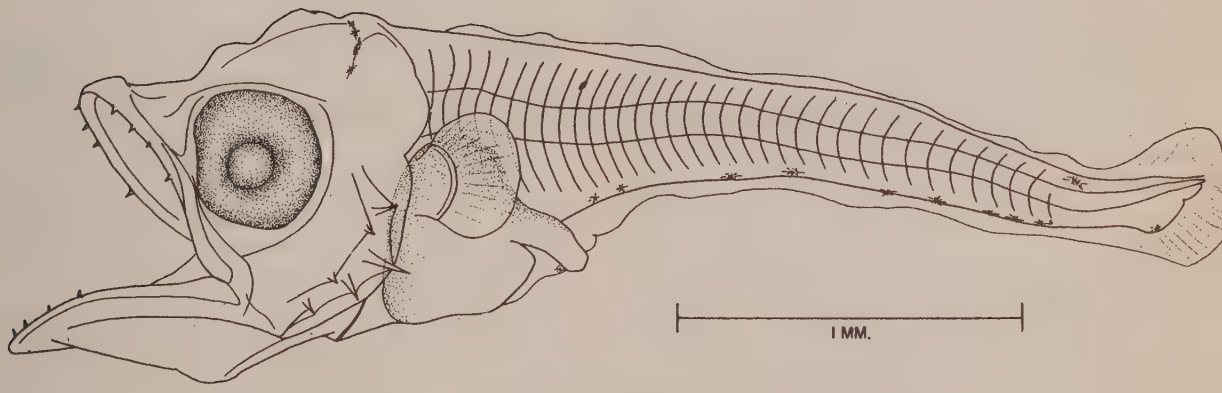


Fig. 13 Auxis type II, 3.5 mm (from Matsumoto, 1959)

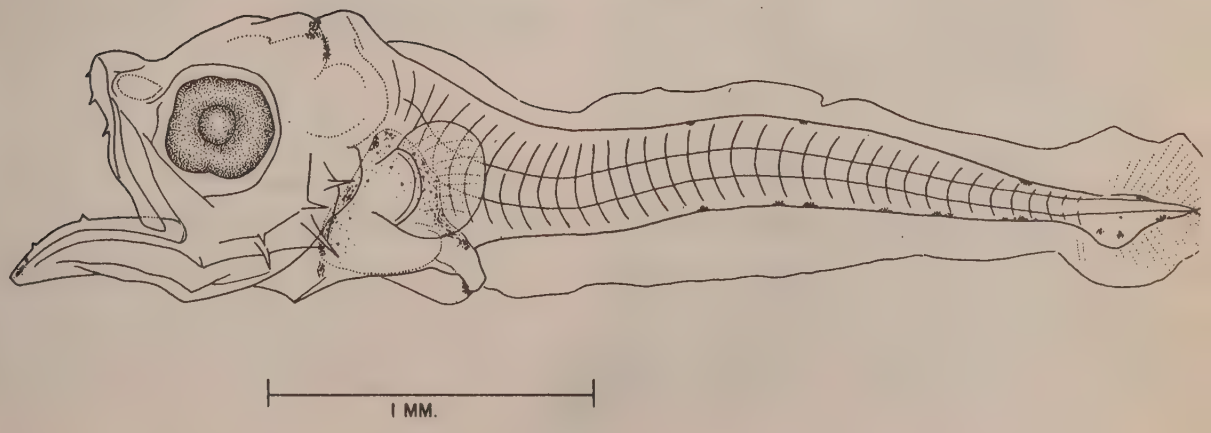


Fig. 14 Auxis type II, 3.7 mm (from Matsumoto, 1959)

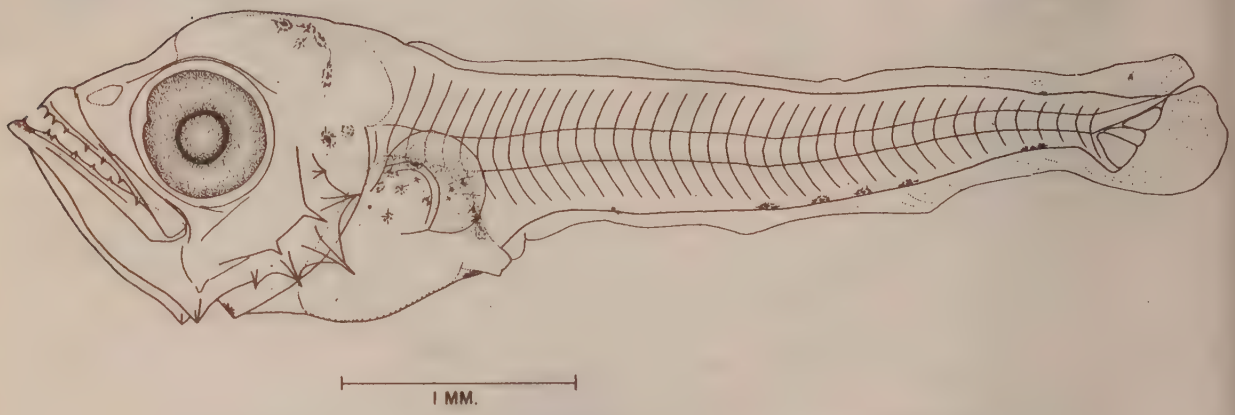


Fig. 15 Auxis type II, 5.2 mm (from Matsumoto, 1959)

Fig. 16 Auxis type II, 7.2 mm (from Matsumoto, 1959)

"(3) Number of spines (less than 9 or 10) in the first dorsal fin. The first dorsal spines are insufficiently developed for comparative purposes in specimens below 7 or 8 mm. The 9.7 mm specimen (Fig. 9), however, possesses a first dorsal fin composed of 9 well-developed spines which closely resemble that of the adult. The first and second dorsal fins are widely spaced, and the initial development of 7 additional small spines are noticed between the end of the first and origin of the second dorsal fins. These spines do not develop to any great length, as noticed in the 25-mm specimens, but are still distinctly noticeable on larger juveniles up to about 50 mm. Except for the anterior 2 or 3 spines, which later develop as part of the first dorsal fin of the adult, these interdorsal spines ultimately become imbedded beneath the outer layer of skin.

"(4) Number of chromatophores in the first dorsal fin. Generally, the first dorsal fin of juvenile Auxis is very lightly pigmented and is almost colorless. The first signs of pigmentation on this fin appear rather late, at about 11.0 mm and the 11.2-mm specimen illustrated here has only 3 large chromatophores. The 13.2-mm specimen also shows few chromatophores. Beyond this size the number of chromatophores seems to increase with growth, but at no stage is this pigmentation conspicuous. The chromatophores themselves are scattered almost evenly throughout the fin membrane, as shown in the 25.0-mm specimen (Fig. 12).

Auxis type II.

"Type II refers to a series of larvae, measuring from 3.5 mm to 7.2 mm, which lack chromatophores along the midlateral line in the caudal peduncle region. This lack, however, is not always consistent, and on some specimens chromatophores are missing on one side only. The smallest specimen (Fig. 13) has a single darkly pigmented spot at the symphysis of the pectoral girdle and chromatophores on both the dorsal and ventral edges of the body in the caudal peduncle region. Unlike the type I specimens, only one chromatophore is present on the dorsal midline of the caudal peduncle region. A long series of 9 well-spaced chromatophores is present along the entire ventral margin of the body. The midbrain is sparsely pigmented and the midsection of the lower jaw has no pigmentation. The myomere count is identical with that found in type I.

"The 3.7-mm specimen (Fig. 14), which was earlier identified as A. thazard (Matsumoto, 1958), appears similar to the 3.5-mm specimen and has therefore been placed in this series.

"A slightly larger specimen, 5.2 mm (Fig. 15), also has the same characteristics as the 3.5-mm specimen, except for the pigmentation on the posterior part of the body. There are 3 very closely spaced chromatophores on the midventral line of the caudal peduncle region, and 4 more widely spaced chromatophores farther forward.

"Several changes occur in the 7.2-mm specimen (Fig. 16). The first dorsal fin consists of 5 spines, and the second dorsal fin is represented by about 11 rays. The anal fin also shows signs of development, and about 7 rays can be distinguished. The anal finlets, like their dorsal counterparts, are hardly noticeable. The caudal fin is quite advanced in development, and its posterior margin is beginning to fork. The ventrals are present, but they are still very small.

"In general only minor changes in pigmentation are evident. Two very close-set chromatophores are present on the dorsal edge of the caudal peduncle, and 2 more similar ones are noticeable opposite them on the ventral edge. Anteriorly, 3 more well-spaced chromatophores are present along the bases of the anal finlets.

"The series stops at about 8 mm, and all specimens above this size are referable to type I."

Matsumoto points out one important observation in discussing the species difference of the type I and type II larvae of Auxis. This is the extreme inconsistency of pigmentation on the midlateral line. In many of the specimens he examined, there were from 1 to 5 chromatophores on one side of the body, but none on the other side. He states that such a wide variation in pigmentation between the two sides of the same fish renders the separation of Auxis into types I and II rather doubtful. He states that on the basis of this variation and also on the fact that the type II series stopped at about 8 mm., one may conclude that the two types are merely variants of a single species.

In the Indo-Pacific region, Auxis larvae have been captured in waters with temperatures that ranged from 22.5° C (72.5° F) to 29° C (84.2° F). The coldest water in which Auxis larvae were taken occurred off the eastern coast of Australia (Matsumoto, 1959).

According to Clemens (1956), larval scombrids most frequently captured under a night light in the tropical eastern Pacific are the frigate mackerel. He states that these larvae are more numerous and widely distributed than the Euthynnus larvae. The larval frigate mackerel outnumber the larval Euthynnus by about 300 to 1 in night light samples collected in areas where larvae of both of these scombrids occurred.

Descriptions and comparisons of morphological features of the juveniles of A. thazard are given by Schaefer and Marr (1948). In their work, they recognized that different species of Auxis may occur in different parts of the world, but since the solution to the problem of specifically identifying the species with which they worked was beyond the scope of their investigation, they referred to the juveniles as A. thazard.

The juveniles were captured in Central American Pacific waters off Costa Rica and northern Panama. These fish were taken with dip nets at night under flood lights. The locations and dates of capture are given in Table III.

Five additional specimens examined by these investigators were supplied by Dr. J. T. Nichols, and these were taken under night light on March 24, 1941, at 04°01' N, 80°26' W. The description of these representative juveniles is quoted from their work (p. 266).

The vertebral count of the specimens examined by Schaefer and Marr agrees with Kishinouye (1923) and Frade and deBuen (1932) but disagrees with Starks (1910). They found that in a 72 mm specimen the haemal arch was first noted to close on the 18th vertebra. This is in disagreement with the report by Kishinouye, who states that the first closed haemal arch occurs on the first caudal vertebra (21st vertebra). Because of this discrepancy, Schaefer and Marr concluded that the specimens with which they worked may, therefore, be juveniles of an undescribed species.

Schaefer and Marr concluded from the vertebral count, the great length of the right lobe of the liver, the presence of a caudal keel, and the absence of an air bladder that the juvenile scombrids they examined belong to the family Katsuwonidae. Because of the large interspace between the dorsal fins and low ray count of the first dorsal, as well as the absence of the elaborate "trellis" of the vertebrae, they deduced that the specimens belonged to the genus Auxis rather than Euthynnus or Katsuwonus. Thus, specific identification must await examination of adult specimens from the area.

Herald (1951) reported on the presence of pseudofins on the caudal peduncle of juvenile Auxis. He found that "two of the three solid ridges which are conspicuous along the side of the tail of adult Auxis actually develop as small, unstriated, fin-like structures." He counted usually 11 soft rays in each Auxis pseudofin and as many as 14 rays were present. He says that these structures have no outstanding anatomical significance. The lengths which frigate mackerel attain before the replacement of these pseudofins by solid ridges takes place is not definitely known.

Table III

Localities of capture of A. thazard in 1947

| Date | Position of station | Number caught | Total length of specimens (mm.) |
|---|---|---|---|
| March 18 | 08°20' N., 84°10' W. | 2 | 67, 68 |
| March 19 | 09°43' N., 85°54' W. | 52 | 21 to 53 |
| May 7 | 08°7'30" N., 83°8'30" W. | 3 | 23 to 41 |
| May 17 | 09°43' N., 85°54' W. | 1 | 42 |

"In the smaller specimens the prominent areas of pigmentation are on the upper and lower jaws, above the snout, around the postero-ventral margin of the orbit, on the upper operculum, between the orbits, along the midline of the body, along the bases of the dorsal and anal fins including the finlets, and around the posterior end of the urostyle. Large chromatophores in the peritoneum show through the body wall along the upper half of the body cavity. None of the fins or finlets bears pigment spots, with the exception of the first dorsal. The first dorsal bears a few scattered chromatophores, largely distributed along the spines. However, the first dorsal in general appearance is virtually colorless... ."

Schaefer and Marr found that with increasing size, the local areas of pigmentation expand. They state (p. 267), "In our largest specimens the head is well pigmented. The dorsal half of the body is uniformly dark. This dark area extends below the midline on the caudal peduncle. The chromatophores in the peritoneum are no longer visible through the thickened body wall, and the ventral surface is unpigmented. Even in our largest specimens none of the fins is heavily pigmented; the caudal is more pigmented than the others."

An interesting discussion on gill raker counts in the juvenile A. thazard is also given by Schaefer and Marr. They state that the gill rakers on the most anterior gill arch of their smallest specimens are very tiny projections and are first apparent near the angle of the arch. As the fish increase in size, the rakers near the angle of the arch increase in length and new rakers are added distally on each arm. They further state that the full complement of rakers is apparently attained at about 50 mm total length.

- Feeding

By examining the stomachs of juvenile A. maru, which were recovered from the stomachs of yellowfin and skipjack, Kishinouye (1924) found that like the juveniles of skipjack, the food of juvenile A. maru consists of larval copepods and decapods.

Clemens (1956) observed the feeding behavior of larval scombrids reared in shipboard aquaria. He stated that the frigate mackerel refused food until the second day, at which time they started to compete for food with the other fishes such as dolphinfish (Coryphaena), jacks (Caranx), pompano (Trachinotus), threadfins (Polydactylus), and pomacentrids (Chromis). Clemens believes this behavior of the frigate mackerel suggests that they had learned to eat the unnatural food that was being offered by watching the other species feeding on it. The food offered included living planktonic organisms, ground flesh of anchovetas (Centengraulis mysticetus), yellowfin tuna (Neothunnus macropterus), oceanic skipjack (Katsuwonus pelamis), and dolphinfish (Coryphaena hippurus), particles of coagulated fish blood, and dolphinfish eggs.

Clemens adds that competition for food appears to be of fundamental importance. He noticed that in a tank with a large number of fish that splashed and moved about the tank at a high rate of speed, voraciously striking at everything in sight, the frigate mackerel soon commenced feeding.

- Rates of: development and survival

In reference to growth of postlarval Auxis, Clemens (1956) noted that the Auxis had a more rapid rate of growth than the Euthynnus. Of five postlarval Auxis placed in an aquarium for observation, he stated that three died several hours later from injuries received in handling. The remaining two measured 20 and 30 mm in total length, and these survived for six days. The smaller frigate mackerel grew about 40 mm. during its six days in captivity while the larger fish grew an estimated 46 mm in six days.

- Periods of: development and survival

Strasburg (1959) reported on an instance of natural mass mortality of larval frigate mackerel in the Hawaiian Islands. He noted that there were two distinct types of larval frigate mackerel in the preserved plankton collection made in the vicinity of Lanai Island, which is one of the smaller members of the Hawaiian chain. One type was clean cut and of normal appearance, while the other type was imperfect with signs of physical deterioration. He hypothesized that these types represented fish which were alive and dead, respectively, just prior to capture. In a simple experiment, he

allowed several fresh, dead specimens to decompose in dishes of sea water, while several other fresh, dead specimens were preserved in formalin. By comparing the appearance of the two types of larvae he found in his plankton collection with the preserved and decomposed specimens, he concluded that large numbers of the larval frigate mackerel he had collected were dead before capture. The definitive cause of death could not be determined. He noted that there were no signs of predation, disease, or parasitism, and starvation could not be definitely excluded as a factor. He tentatively hypothesized that the mass mortality was due to the passage of the larvae through an area having marked discontinuities in its surface water temperature.

- Parental care

The eggs, larvae, and juvenile stages of the frigate mackerel are, like the adults, completely pelagic. There is at present no evidence that the adult of the species cares for the eggs or young.

- Parasites and predators

Mead (1951), working with postlarval tuna from the Pacific Coast of Central America, found two juvenile Auxis, 79 and 117 mm. in fork length, in the stomach of a large yellowfin caught on May 6, 1949, at 11°40' N. latitude, 91°00' W. longitude. He tentatively identified these two specimens as A. thazard on the basis of gill raker count.

Kishinouye (1923) reported that he received several immature specimens of A. maru which were obtained from the stomach of striped bonitos, caught off Awakunijima, Okinawa-ken (Ryukyu). They ranged in size from 11 to 17 cm. in length. The largest specimen resembled the adult form, but of the smaller specimens, ranging from 11 to 13 cm. in length, he stated that they were remarkably slender. In the small specimens, the skin was more or less damaged by the gastric juice and the markings were not seen, but on the largest specimen, he noted that there seem to be some transverse bands.

One interesting observation about the predator-prey relationship among the scombroids is given in a work by Kishinouye (1926). He states that when the mature fish of the Plecostei, which are among the fastest swimmers, are feeding on the juveniles of other kinds of fish, it is not unusual to find as many as twenty or thirty individuals in the stomach of one fish. However, when the Plecostean fishes are feeding on the juveniles of their own kind, only a few specimens at most are found in any one stomach.

### 3.3 Adult history

#### 3.3.2 Hardiness

Kishinouye (1923) pointed out that the salinity of the water most suitable for scombroid fishes differs very greatly for different species. For the fishes of the family Scombridae and Cybiidae, he gave a density range of 1.022-1.025, while for the Plecostean fishes, which he claims prefer water of a higher density, he gave a density range of 1.025-1.027. However, he added that Auxis are sometimes found in littoral waters of low density.

#### 3.3.3 Competitors

In general, the frigate mackerel live in competition with other tunas, mackerel, and bonitos during all stages of their life. In section 3.4.2 are listed some of the organisms found in the stomach of frigate mackerel. Examination of reports on food studies of bigeye, yellowfin, and albacore indicates that most of the organisms Auxis feed on are also a part of the diet of these tunas (King and Ikehara, 1956; Iversen, 1961).

It may be concluded that most pelagic fishes are potential competitors of Auxis.

#### 3.3.4 Predators

In his study of the spearfishes of the central Pacific, Royce (1957) found that several tunalike fishes, some identifiable as Auxis, were present in the stomachs of striped marlin (Makaira audax) taken in equatorial waters. Nakamura (1942), in examining the food contents of 163 stomachs of black marlin (Makaira ampla) taken in the east Philippine Sea, found that 53 stomachs contained squid, 11 contained Leiognathus, 12 contained Balistes, 11 contained Auxis, and lesser amounts of some 9 other genera of fish.

In a report published in 1936 dealing with the food habits of yellowfin tuna (Neothunnus

macropterus) taken in the Celebes Sea, Nakamura commented that it is not known whether there is a point of satiation in the feeding of the yellowfin, but in the stomach of a yellowfin 137 cm in length, he found three specimens of Auxis sp. which averaged about 30 cm in length along with various other items.

From the examination of the stomach contents of yellowfin (Neothunnus macropterus), skipjack (Katsuwonus pelamis), oceanic bonito (Euthynnus yaito), and dolphin (Coryphaena hippurus), Ronquillo (1953) concluded that tunas apparently do not choose their food, but eat any swimming animal available. Fish evidently is the chief food item of the tuna. Among larvae and juvenile fishes frequently appearing in the stomachs of the tunas and dolphins he examined were Acronurus, Caranx, Holocentrus, Gempylus, Auxis, Dactyloptena, Trichiurus, balistids, monacanthids, tetraodontids, triacanthids, chaetodontids, and bramids. The specimens of Auxis were among the larger fish included in the food item. Ronquillo stated that a few specimens of Auxis about 250 mm in fork length were found in the stomachs of yellowfins 674 mm in fork length.

From his study on the food of the tunas, Kishinouye (1917b) found that many juveniles of tunas can be collected. In the stomach of one yellowfin, he found a juvenile bigeye swallowed together with flying fish and several specimens of A. maru. Another yellowfin stomach had a juvenile albacore about 10.8 inches long along with some A. maru.

In a comparative study of food of bigeye and yellowfin tuna in the central Pacific, King and Ikehara (1956:table 11) list A. thazard occurring in 2.7 percent of the yellowfin stomachs examined and in 1.2 percent of the bigeye stomachs examined.

### 3.3.5 Parasites and diseases

Of the scombroid fishes in general, Kishinouye (1923) stated that external parasites are mostly copepods and trematodes. He found that these are usually attached to the upper surface of the pectoral fin, to the inner side of the opercle, to the gill lamellae, in the nasal cavity, and in the mouth cavity. He stated that, in general, these parasites are not numerous, although sometimes they occur in large batches.

Kishinouye also discusses internal parasites of the scombroid fishes and he says that these are chiefly trematodes and nematodes, living in the alimentary canal, the circulatory system, muscles, and tissues of the viscera. He noted that species of Distoma use Acanthocybium, tunnies, and bonitos as hosts.

### 3.3.6 Greatest size

Tinker (1944) states that the frigate mackerel in Hawaiian waters is smaller than the skipjack and may reach a weight of about 10 pounds. However, in schools, they seldom exceed 5 pounds in weight. Gosline and Brock (1960) state that the Hawaiian frigate mackerel is generally less than 10 pounds in weight. Fish (1948) is of the opinion that the frigate mackerel does not get over 5 pounds. Kishinouye (1923) states that the A. hira grows to a weight of about 1.5 kg (about 3.3 pounds), while of the A. maru, he says that this fish is the smallest species in his order Plecostei and grows to a weight of about 640 g (about 1.4 pounds).

## 3.4 Nutrition and growth

### 3.4.1 Feeding (time, place, manner, season)

In discussing the habits of the scombroids in general, Kishinouye (1923) stated that they generally swim to the shallower strata of water at night and return to the deeper layer in the daytime. He believes that they are probably following the movement of the plankton and also the movement of those fishes that feed on the plankton.

Imamura (1949) discussed the manner in which A. maru and A. hira feed. He maintains that these fishes use their caudal fins to hold their position in the swift currents and in this way capture their food, which drifts down to them. In the morning and evening and also during periods of cloudy weather, they sometimes migrate away from the swift currents in search of food and school near the surface.

From his study on the ecology of teleosts in Japanese waters in relation to brain

morphology, Uchihashi (1953) concluded that A. tapeinosoma seeks food by sight and can also detect prey by their lateral line senses.

### 3.4.2 Food (type, volume)

Tester and Nakamura (1957) examined the stomach contents of two frigate mackerel taken off Kaneohe Bay, Oahu, Hawaii, and found that one contained numerous crab megalops and stomatopod larvae. The other stomach examined contained 8 crab megalops, numerous stomatopod larvae, 2 anomuran larvae, and a small octopus. These fish were 33.2 and 36.6 cm in length.

Kishinouye (1923) stated that Auxis sp. generally feeds on small plankton and small fishes, such as Atherina, Stolephorus, Spratelloides, and immature forms of Engraulis.

Okada (1955:137) states that the marusōda, which he calls A. tapeinosoma, "always lives far off the coast, in shoals, and feeds on small pelagic organisms, anchovies, silvery anchovies, silversides and other small fishes."

### 3.4.3 Relative and absolute growth patterns and rates

No information is available on the relative and absolute growth pattern and rates of the adult frigate mackerel. What little information is available on the absolute growth rate of juvenile frigate mackerel has been discussed in section 3.2.1, Rates of: development and survival.

## 3.5 Behavior

### 3.5.1 Migration and local movements

Imamura (1949) states that in Japan the general term skipjack (katsuo) includes four species. These are the magatsuo (Katsuwonus pelamis), the sumagatsuo (Euthynnus yaito), the hagatsuo (Sarda orientalis), and the sōdagatsuo (Auxis sp.). He says that these fish live in tropical areas which have high water temperatures, and migrate into Japanese waters with the Kuroshio in the summer.

Imamura discusses the migration of the two species of sōdagatsuo, the marusōdakatsuo (A. maru) and the hirasōdakatsuo (A. hira). He states that both species prefer high temperatures and live in the Kuroshio. Of the marusōdakatsuo (A. maru), Imamura says that it is a coastal fish that prefers the swift currents around promontories and enters the bays in schools. On the Pacific coast of Japan, they migrate as far north as Shiriya Misaki in Aomori Prefecture (about 41° N.) and also enter the Japan Sea.

Imamura states that the hirasōdakatsuo (A. hira) has a body which is more flattened laterally than the marusōdakatsuo and is more pelagic in nature. It lives around islands and promontories and its habits are much like that of the sumagatsuo (E. yaito). The hirasōdakatsuo do not form large schools and are sometimes seen mingled with the true skipjack. About the time of the autumn equinox (September 22 in the Northern Hemisphere), the schools which have been migrating northward turn south and begin their southward migration.

Kishinouye (1923) reported that the Auxis approach close to shore during the warm seasons, often in very large schools. During the colder winter months, the fish swim in the deeper strata of water.

Uchihashi (1953) made an ecological study of the Japanese teleosts in relation to the brain morphology. He noted that the marusōda (A. tapeinosoma) is a type of fish that swims in groups during the night as well as during the day.

Okachi (1958) found from his studies of the catch statistics of frigate mackerel taken in the Japan Sea that along the coast of the Japan Sea, west of Ishikawa Prefecture and on the west coast of Kyushu, there are a number of months when no catch is recorded, but he states that in general small quantities are taken throughout the year. He assumes that there are some schools which pass the winter in these regions. While he was not able to detect a clear trend of northward migration by examining the peak in the catch, he found an extremely clear trend of southward movement of the frigate mackerel apparent in

Aomori, Akita, and Yamagata Prefectures in October, west of Niigata to Yamaguchi and in Fukuoka, Saga, and Nagasaki Prefectures in November, and in Kagoshima Prefecture in December which produces the bulk of the annual catch (Table IV: table 5 of Okachi,1958).

Okachi further states that he is uncertain as to the reason for the small catch of frigate mackerel in the Japan Sea while the fish are on their northward journey. He finds that the northward movement begins around June and is more active around July and August. At about this time, the force of the Tsushima Current flowing into the Japan Sea is also at its height, and he deduced that the frigate mackerel move north in off-shore waters together with the main stream of that current. From October, however, the schools that moved north come close to the coast because of the wind-driven currents headed toward Japan under the influence of the northerly to northwesterly seasonal winds which begin to predominate at about this time. Thus, he concluded that the opportunities to enter the trap nets are increased. He does not discount the fact that there may be other differences, such as in the ecology of the frigate mackerel during the periods of northward and southward movement, the schooling characteristics of the fish, differences in swimming depth, and whether or not their migration routes approach the coast.

In an analysis of the behavior of some marine teleosts, Uchihashi (1953) concluded that A. tapeinosoma is a type of fish that is very quick in behavior and also noted that the fish has phototaxis response.

### 3.5.2 Schooling

It is apparent from the reports contained in the literature that the schooling instinct of the frigate mackerel is very strong. Nakamura (1937) reported that dense schools of Auxis sp. migrate into the coastal waters of Taiwan during certain times of the year. Shapiro (1948) reported that A. hira is abundant in the Ryukyu Islands in mid-summer. Shoals of hundreds of individuals were reported to appear in the southwestern part of Australia by Serventy (1941).

In Hawaiian waters, frigate mackerel are occasionally found mixed with schools of Euthynnus yaito (Gosline and Brock, 1960). Matsumoto (1960) has reported capturing

Table IV

Mean catch of frigate mackerel by month and prefecture
(from January 1952 to July 1957)

Unit of catch: 1,000 kan (= 3.75 metric tons)

| Prefecture | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Aomori | - | - | - | - | - | 0.1 | 0.9 | 1.7 | 0.7 | 3.1 | 0.6 | - |
| Akita | - | - | - | - | - | 0.1 | 0.6 | 1.1 | 1.3 | 1.7 | 0.4 | - |
| Yamagata | - | - | - | - | - | - | - | 0.1 | 0.1 | 0.5 | 0.1 | - |
| Niigata | 0.2 | 0.1 | - | - | 0.1 | - | 3.5 | 3.1 | 4.5 | 7.7 | 17.9 | 0.7 |
| Toyama | 2.0 | 0.2 | - | - | - | 0.1 | 0.4 | 0.4 | 0.5 | 36.9 | 100.5 | 60.3 |
| Ishikawa | 0.3 | - | 0.1 | 0.1 | - | - | 2.5 | 1.2 | 4.1 | 5.5 | 10.5 | 5.7 |
| Fukui | 0.3 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 3.5 | 17.5 | 4.9 | 5.5 | 6.7 | 1.9 |
| Kyoto | 0.3 | - | 0.1 | 0.2 | - | 0.3 | 0.3 | 0.2 | 0.5 | 5.1 | 10.9 | 7.7 |
| Hyogo | 0.1 | - | - | - | 0.2 | 0.1 | - | 0.1 | 0.3 | 0.3 | 0.7 | 0.5 |
| Tottori | 0.2 | 0.2 | - | - | 0.1 | - | 0.1 | 0.6 | 2.3 | 5.1 | 1.3 | 0.3 |
| Shimane | 0.3 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.8 | 1.5 | 2.9 | 7.5 | 0.5 |
| Yamaguchi | 1.9 | 0.8 | 0.5 | 0.3 | 0.2 | - | 0.3 | 1.8 | 7.1 | 8.0 | 21.1 | 12.7 |
| Fukuoka | 0.1 | - | - | - | - | 0.1 | 0.1 | 0.1 | 1.5 | 0.3 | 1.3 | 0.2 |
| Saga | 0.6 | 0.1 | 0.1 | - | - | - | - | 0.1 | - | 0.1 | 0.8 | 0.5 |
| Nagasaki | 6.9 | 0.7 | 0.7 | 0.2 | 0.3 | 0.5 | 1.5 | 2.3 | 5.1 | 17.1 | 29.3 | 27.7 |
| Kumamoto | - | 1.2 | 0.1 | 2.4 | 1.1 | 0.1 | 0.3 | 0.4 | 0.3 | 0.6 | 0.2 | 0.2 |
| Kagoshima | 5.3 | 4.2 | 5.5 | 17.0 | 19.2 | 24.2 | 38.2 | 17.3 | 11.3 | 12.1 | 14.1 | 14.9 |

both A. thazard and A. thynnoides from the same school (see section 2.1). Matsumoto (1959:20) wrote, "It is interesting to note that both long- and short-corseletted forms taken in Hawaiian waters were from the same school. Through correspondence with Dr. S. Jones, Chief Research Officer at the Central Marine Fisheries Station, Mandapam Camp, South India, it was learned that two types of Auxis also occur in the Indian Ocean, and that they are frequently found together in the same school. Similar observations were also reported by Kishinouye (1915)."

Imamura (1959) states that A. hira found in Japanese waters do not form large schools. They are occasionally found mingled with skipjack.

### 3.5.3 Reproductive habits

See sections 3.1.1, 3.1.3, and 3.1.6.

## 4 POPULATION (STOCK)

### 4.1 Structure

#### 4.1.1 Sex ratio

No information is available on the structure of the population in relation to sex ratio. However, an account of changing sex ratio on the fishing ground throughout the season is mentioned in the work by Kishinouye (1923). He states that generally, among the scombroids, the male fish arrive first on the fishing ground. By the middle of the season, the sex ratio is nearly equal. The end of the fishing season finds female fish predominating on the fishing ground.

#### 4.1.3 Size composition

In the summary of catches off Kaneohe Bay, Oahu, Hawaii, Tester and Nakamura (1957) listed a total of 23 frigate mackerel taken between the period May 1951 to October 1954. Although the number of fish taken was small, this is perhaps indicative of the size composition of the population of frigate mackerel from this area. Tester and Nakamura noted that the 23 frigate mackerel averaged 1-1/2 pounds and ranged from 1 to 2-1/2 pounds.

Warfel (1958) reported that the average weight of A. thazard and A. tapeinosoma taken from Philippine waters is about 12 ounces.

Of the frigate mackerels found in Australian waters, Roughley (1951) stated, "With the possible exception of the leaping bonito, the frigate mackerel is the smallest of the Australian tunas, its weight rarely exceeding 3 pounds."

### 4.4 Mortality, morbidity

#### 4.4.2 Factors or conditions affecting mortality

An instance of natural mass mortality of frigate mackerel larvae in Hawaiian waters was reported by Strasburg (1959). A summary of his findings is given in section 3.2.1 under Periods of: development and survival.

### 4.6 Relation of population to community and ecosystem, biological production, etc.

As the Auxis is an open water form and lives in an environment where many carnivores are present, it is most likely predation rather than competition for food that limits its abundance. Evidence of predation is apparent in many food studies made on tunas and spearfishes, and both juveniles and adult frigate mackerels fall prey to large predators.

It has been hypothesized that marked discontinuities in surface water temperature may be responsible for mass mortality of larval frigate mackerel (Strasburg, 1959). (See section 3.2.1, Periods of: development and survival).

## 5 EXPLOITATION

### 5.1 Fishing equipment

#### 5.1.1 Fishing gear

The A. maru is caught in pound nets, set nets, drift nets, and by rod and line (Kishinouye, 1923). Serventy (1941) states: "Shoals of hundreds of individuals appear during the summer months at coastal fishing resorts in southwestern Australia and in the region of Sydney, and numbers may be captured by beach seining. It is not usually taken by ordinary trolling gear like the other tunas."

Tester (1952), on the other hand, in trying to establish tuna and other pelagic fishes in ponds and tanks, reportedly took most of his fish by trolling. Fishing took place in an area off Mokumanu (Bird Island), near Kaneohe Bay, Oahu, Hawaii. He used a variety of relatively small lures, such as greenish or brownish pliable-rubber imitation squid, gray or red metal-headed imitation squid with white rubber arms, and red or white metal-headed jigs. Between the period from January 18 to October 18, 1951, 381 fish were taken, of which 280 were tuna (Thunnidae). Twenty-two of the tunas taken were frigate mackerel (A. thazard) ranging from 1 to 2-1/2 pounds (32 to 37 cm. in length). Tester stated that frigate mackerel, tunny, and yellowfin were caught sporadically from May or June to September or October.

Warfel (1952) says that of the two species of frigate mackerels known in Philippine waters, namely A. thazard and A. tapeinosoma, the former predominates in the commercial catch. In addition to purse seines, the frigate mackerels are also taken by fish corrals.

The pole-and-line, livebait method of fishing is also used in taking frigate mackerels. One incident of frigate mackerels being taken by this method in Hawaiian waters was discussed in section 2.1.

In a publication giving the morphometric measurements of Pacific scombroids, Dung and Royce (1953) recorded that the frigate mackerels from the Hawaiian Islands were taken by pole-and-line and trolling gear, while frigate mackerel from Japan were recorded as being taken by pole-and-line fishing.

In Taiwan, large numbers of set nets are placed everywhere along the eastern coast to capture the sōdagatsuwo (Auxis sp.) (Nakamura, 1937).

Okachi (1958) states that in the Japan Sea and East China Sea regions, the main item of gear used in the frigate mackerel fishery is trap nets, which produce most of the catch in both of these regions. Consequently, the catches are highest in the Prefectures of Niigata, Toyama, Ishikawa, Fukui, Kyoto, and Yamaguchi, where trap net fishing is active. In the East China Sea region, Nagasaki and Kagoshima Prefectures produce the bulk of the catch, with only small quantities being taken elsewhere.

The trap net or fixed net fishing as practiced in Japan consists of a leading net that may be as deep as 100 meters and stretch out as far as 4,000 meters offshore (Anonymous, 1957). The cube-shaped bag or pound net is set near the coast and may be 5 meters deep. Fishermen tending these trap nets wait for migration of a school of fish that are moving close to shore. Nets with larger meshes are used mainly for the capture of large species of fish such as mackerel, yellowtail, and tuna, while nets with smaller meshes are used for the capture of small species like the sardine.

These fixed nets are generally drawn up twice a day, once in the morning and once in the evening. However, the time varies with the quantity of fish captured in the net.

#### 5.1.2 Fishing boats

Although much of the commercial fishing for the Auxis is done with trap or set nets,

there are occasional catches made by pole-and-line fishing. In Japan and Hawaii, the pole-and-line, livebait method of fishing is primarily for skipjack.

The present day Japanese skipjack boats are either of wood or steel construction. Wooden vessels range from 60 to 135 tons and average about 80 to 90 tons. Steel vessels are generally much larger, ranging from about 100 tons to about 300 tons with the majority in the 120-180 ton class (Imamura, 1949).

The Hawaiian skipjack boats are much smaller than the Japanese vessels, and although these boats evolved from the Japanese sampan-type tuna boats, modifications in design have made the Hawaiian boat of today a distinct type of vessel adapted to local needs and conditions. The boat size ranges from 29 to 92 feet in overall length with the majority about 70 to 88 feet in length (June 1951).

Skipjack boats are equipped to carry live bait and scout the offshore waters in search of fish schools.

## 5.2 Fishing areas

### 5.2.1 General geographic distribution

In a discussion of the principal marine fisheries of the Philippine Islands, Manacop (1952) listed the fishing areas for the frigate mackerel (A. thazard) in Philippine waters. These areas are the northern and northwestern Zambales coast, Manila Bay, Batangas and Balayan Bays, Rahay Gulf and Burias Pass, San Miguel Bay, southern Zamboanga, and the Sulu Archipelago.

See also sections 3.5.1, Migration and local movements and 5.4.3, Catches.

### 5.2.2 Geographical ranges (latitudes, distances from coast, etc.)

See sections 3.5.1 and 5.1.

### 5.2.3 Depth ranges

Kishinouye (1923) gave the range of the vertical distribution of A. hira as being from the surface to about 45 meters.

## 5.3 Fishing seasons

### 5.3.1 General pattern of fishing season

See section 3.5.1, Migration and local movements

### 5.3.2 Duration of fishing season

See section 3.5.1, Migration and local movements

### 5.3.3 Dates of beginning, peak, and end of season

Shapiro (1948) states that A. hira appears in abundance in the Ryukyu Islands during July. This is somewhat later than the time that the migrating schools of skipjack pass through the Ryukyu waters on their annual movement into Japanese waters.

In the Taiwan trap-net fishery, large numbers of set nets are placed along the coast to capture the very dense schools of sōdagatsuwo (Auxis sp.) which migrate into the coastal water from April to the first part of July (Nakamura, 1937).

## 5.4 Fishing operations and results

### 5.4.2 Selectivity

The set-net fishery for Auxis as it is carried on in Taiwan is not very selective according to Nakamura (1937). He states that besides the Auxis, other miscellaneous species including cybiids and spearfishes are caught in these set nets.

### 5.4.3 Catches

In Hawaii, the commercial importance of the frigate mackerel is very slight. Gosline and Brock (1960) report that the frigate mackerel is taken only incidentally in fishing operations. Occasional catches of this species are made while fishing schools of Euthynnus yaito.

Frigate mackerel taken in Australia are also of very little commercial value (Serventy, 1941). Although it has been reported that large schools of this species appear during the summer months in southwestern Australia, specimens that appear on the

markets are usually disposed of for bait. Roughley (1951) added that in Australia the economic feasibility of commercial exploitation of this species has yet to be demonstrated.

Japan lands far more frigate mackerel than any other country, and is in fact the only country which fishes the species in commercial quantities. Between the years 1952 to 1959, the average catch of this species amounted to 21,800 metric tons (1 metric ton = 1.102 short tons) with a low of 15,600 metric tons in 1953 and a high of 25,900 metric tons in 1956 (FAO, 1954-55, 1959).

Okachi (1958) studied the distribution of the Auxis in the Japan Sea by examining the catch statistics. In his report, he states that almost all of the Auxis in the Japan Sea are marusōda (A. maru), while hirasōda (A. hira) are taken only rarely. Looking at the catch by regions in Japan, he found that the Pacific southern region has more than 60 percent and the Pacific central region has about 20 percent, while the Japan Sea and East China Sea regions produce only about 10-15 percent of the catch. Furthermore, he found that the catches from the Japan Sea northern region and the East China Sea region are about equal, while the catch of the Japan Sea western region, which lies between these two, is smaller than either of them.

The annual catch of frigate mackerels in Japan is shown by regions for the years from 1952 to 1956 in Table V. (Okachi, 1958: table 6). Okachi states that for the Japan Sea between 1952 and 1956, the largest catch of frigate mackerel was in the year 1954, when approximately 570,000 kan (1 kan = 8.27 pounds) was landed. It can be seen from the table that the middle and south Pacific regions had the highest production of frigate mackerels.

### 5.6 Fish farming, transplanting, and other intervention

The only information available under the heading of transplanting of frigate mackerel may be found in the work by Tester (1952). During 1951, Tester attempted to catch various species of tuna, transport them in a ship's livewell, and establish them in ponds and tanks at the Coconut Island branch of the Hawaii Marine Laboratory. The purpose was to provide specimens for a study of the reaction of tuna to various types of stimuli.

Tester caught 22 frigate mackerel between January 18 and October 18, 1951. Of these, six were successfully transported to shore. He noted that their behavior on deck and in the livewell of the vessel was very similar to that of the skipjack in that when landed, the fish gave convulsive shudders. He stated, however, that the frigate mackerel did not bleed profusely at the gills like the skipjack. He was more successful in transporting frigate mackerel back to the ponds as compared with skipjack, and this was attributed to the greater swimming room in the livewell resulting from the frigate mackerel's smaller size. Those that survived the trip back to the ponds were, however, frequently bruised and battered.

Table V

Yearly catch of frigate mackerel by region

Unit of catch: 1,000 kan (= 3.75 metric tons)

| Region | Year | | | | |
|---|---|---|---|---|---|
| | 1952 | 1953 | 1954 | 1955 | 1956 |
| Grand total | 6,418 | 4,154 | 5,494 | 6,250 | 6,913 |
| Hokkaido | 11 | 9 | 10 | 14 | 10 |
| North Pacific | 153 | 199 | 92 | 206 | 454 |
| Middle Pacific | 1,523 | 784 | 945 | 1,221 | 2,021 |
| South Pacific | 4,335 | 2,537 | 3,574 | 3,776 | 3,757 |
| East China Sea | 147 | 256 | 287 | 457 | 272 |
| West Japan Sea | 108 | 188 | 407 | 470 | 222 |
| North Japan Sea | 119 | 164 | 162 | 96 | 168 |

During May and June of 1951, Tester introduced three frigate mackerel, one little tunny, and six yellowfin into one of the two ponds at Coconut Island. The frigate mackerel dashed wildly across and around the pond. One battered itself on the coral sides of the pond and died within a few minutes. The remaining two swam rapidly for a short time, then disappeared in deep waters of the pond and were not seen again. He presumed that they died within a short time.

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# THE EFFECT OF SURFACE ACTIVE AGENTS ON THE GROWTH OF MARINE PHYTOPLANKTON.

Ravenna Ukeles, U.S. Bureau of Commercial Fisheries, Biological Laboratory, Milford, Connecticut.

Experiments were undertaken to determine the effect of a number of surface active agents on the growth of motile and non-motile chlorophyll bearing protists, that are marine or brackish water phytoplankton species. Six nonionic detergents were tested (Igepal CO surfactants) that are derived from the same hydrophobic material (nonylphenol) and differ only in the amount of hydrophilic substance (ethylene oxide) combined. By increasing the amount of ethylene oxide in relation to the nonylphenol, a series of products with different hydrophobic-hydrophilic balances are obtained. Results show that toxic concentrations vary widely with the individual species. Growth of sensitive species was inhibited by some members of the series at concentration levels of .001% but resistant species were not affected by 1.0% of the same agents. Comparative tests showed that for sensitive species toxicity and inhibition of growth were directly related to the percent of hydrophilic component.

Three nonionic surface active agents derived from the condensation of fatty acids and their derivatives with ethylene oxide (Tween 20, Tween 40 and Tween 80) were also included in this study. These compounds were generally less toxic than the nonionic detergents of the Igepal series.

The specific differences in the response of individual species are discussed.

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California Association of Chemistry Teachers

**John W. VanLandingham**
Bureau of Commercial Fisheries
Washington, D. C.

# Inorganic Nutrients in the Sea

In this modern age of space consciousness and sub-space exploration, most of us remain unaware of a less spectacular but equally determined thrust into the inner space of the great oceans and seas covering more than two thirds of the earth's surface. The pressure barrier encountered in this submarine world has been just as effective in limiting man's exploration of the ocean depths as the thermal barrier has been in postponing his direct entry into the fringe areas of interplanetary space, long after he had achieved the rocket capability to do so.

Today the major governments of the world are pouring great sums of money and expending much time and effort into a study of the chemical, physical, and biological properties of the marine environment.

The purpose of the discussion here presented is threefold: to illustrate briefly the practical factors which make such research necessary, to discuss the inter-relationship of the above mentioned properties, and to present a semiquantitative, tridimensional study of the distribution of representative inorganic nutrient materials. The most representative of these nutrients are phosphate-phosphorous and nitrite or nitrate-nitrogen. The scope of this paper will be limited to inorganic phosphate and dissolved oxygen.

Dissolved oxygen is being discussed for three reasons: firstly, it is just as vital to the welfare of the marine organism as are the nutrients; secondly, because it is important to the physical oceanographer in his study of the structure and transport of water masses; and finally, because there is a unique relationship between the distribution of dissolved oxygen and that of the nutrients.

Most people might suppose the oceans to be rather homogenous masses of water in which fish and other organisms are randomly distributed. However, years of chemical, physical, and biological research have shown such conceptions to be erroneous. We now know that the chemical and physical properties of sea water vary considerably with respect to both the horizontal and vertical dimensions of the oceans. Paralleling this variability in the properties of sea water we frequently find a systematic diversification (or in some cases limitation) of the bio-types encountered in any particular environment (*2*, *3*).

Since the harvest of the sea is a vital factor in our economy it has become increasingly important to study this problem of nutrient distribution and its relationship to the biological population on an ever expanding scale. Any such study of nutrient distribution must first consider the structure of the oceanic water masses. The most important aspect of this structure involves the vertical profile of the water from the surface to the bottom. This column may be divided into three zones, the uppermost of which is called the euphotic or photosynthetic zone. This is the layer of the water mass in which the intensity of the penetrating sunlight is sufficient to provide the photochemical energy required by the chlorophyll bearing organisms. This zone extends to a depth of 100 or 200 m (*1*, *4*) depending upon the clarity of the water and the intensity of the ambient sunlight. The euphotic zone is the most heavily populated region in the water column and is the one which is most seriously affected by climatic conditions at the surface. The predominant life forms in this zone are the phytoplankton and zooplankton, the microscopic plants and animals of the sea.

Far below the euphotic zone lie the abyssal depths where conditions are quite different from those near the surface. Here turbulence and light penetration are practically nil, and abyssal current velocities are almost imperceptible compared to those in the upper layers. Abyssal water is isolated from the sunlit euphotic zone by the midwater region, a zone of gradual but continuous change in physical properties and in nutrient concentration. The mid-water zone is usually preceded by a distinct layer of water which is characterized by rapid changes in its physical properties. The abrupt nature of these changes is responsible for the descriptive name "discontinuity layer" (*5*) which has been applied to this zone. The thickness of the discontinuity layer as well as the depths of its upper and lower boundaries are quite variable. The upper limit frequently reaches well up into the euphotic zone and the lower boundary may extend down to 200 m (*8*). This zone is just as important to the marine community as is the euphotic zone. Many of the larger forms of marine animals appear to prefer the lower temperature beneath the euphotic zone but in many cases will ascend into this region to forage for food (*11*).

### Vertical Transport of Water and Nutrients

In Figure 1 we have a schematic representation of the life cycle in the sea; beginning with the nutrient chemicals at the bottom of the chart, progressing upward through the phytoplankton, branching on around

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to include the zooplankton and fish and finally returning again to the nutrient materials to complete the cycle. The nutrient cycle actually begins in the land masses of the earth, and as a rule, in the higher altitudes of these land masses. Here we have heavy rainfall situations predominating, with concurrent leaching of the soluble nutrient materials from the soil which run off, through the streams and rivers, and eventually drain into the sea. This alluvial run-off, by reason of its greater freshness, is less dense than sea water. Therefore it tends to spread out on the surface of the sea and is carried into the open ocean by the prevailing surface currents. When these nutrients come in contact with the marine environment they are eventually consumed by the phytoplankton and assimilated into

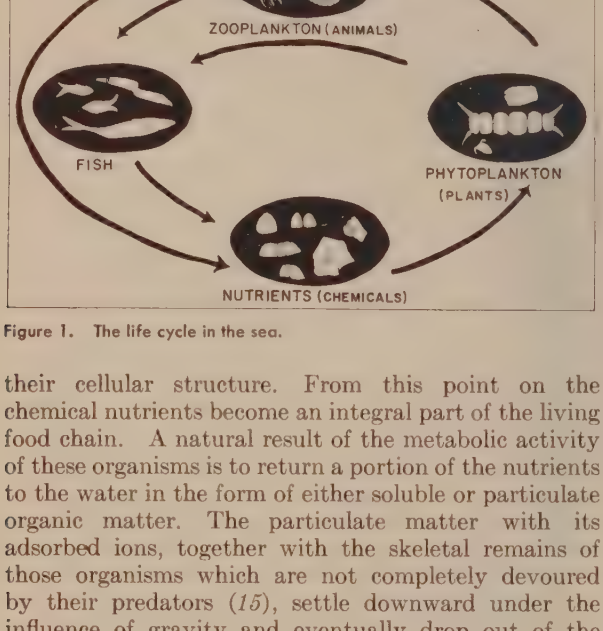



Figure 1. The life cycle in the sea.

their cellular structure. From this point on the chemical nutrients become an integral part of the living food chain. A natural result of the metabolic activity of these organisms is to return a portion of the nutrients to the water in the form of either soluble or particulate organic matter. The particulate matter with its adsorbed ions, together with the skeletal remains of those organisms which are not completely devoured by their predators (*15*), settle downward under the influence of gravity and eventually drop out of the euphotic and discontinuity zones into the quiet waters of the midwater and abyssal depths. During the sedimentation process the particulate matter is attacked by various species of bacteria including those of the chemosynthetic variety. As a result of this bacterial decomposition some of the nutrient materials are regenerated in their soluble inorganic forms. The final stage in this nutrient cycle should then be to return the regenerated material to the euphotic zone where it would again become available for consumption by the phytoplankton.

Such vertical transport of water and nutrient material can take place by several means. Figure 2 illustrates one variety of vertical transport called upwelling. In this particular case a wind blowing parallel to the coast line of a land mass displaces surface water offshore at an angle with the direction of the wind. The viscosity effect of this surface current tends to pull nutrient-rich deep water up the sloping shelf of the land mass and disperse it in the euphotic zone. Another type of upwelling occurs when a abyssal current impinges upon a submarine ban (Fig. 3). On the current side of the shoal abyss water is deflected up toward the surface and if the bank are high enough and the velocity of the current great enough this deep water reaches the euphotic zon Notice also that on the leeward side of the shoal wat is pulled upward by an eddy effect. A similar conditio occurs when a surface current impinges upon an islan mass (Fig. 4). Here, however, the nutrient layer deflected away from the surface on the current side the land mass, but again on the leeward is force upward by an eddy effect.

Vertical water transport sometimes occurs far fro the influence of land masses or sea mounts. Such situation develops when a warm tropical water ma converges with one of significantly lower temperatur Here the thermal difference between the two wat masses creates a great deal of vertical turbulence an mixing all along the points of juncture (*9*). Th several zones of diffusion are represented in Figure by the varicolored bands. Another mechanism f vertical transport of nutrients is called vertical edd diffusion (*6*). This is a cyclical phenomenon produce by wave action on the surface which creates a series

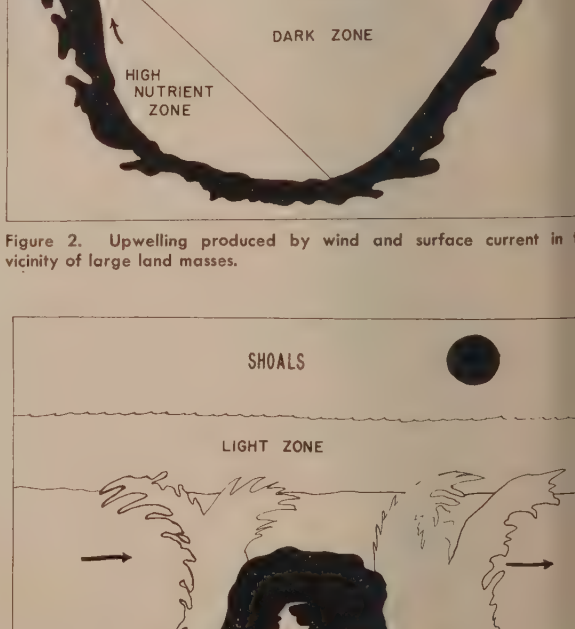



Figure 2. Upwelling produced by wind and surface current in vicinity of large land masses.

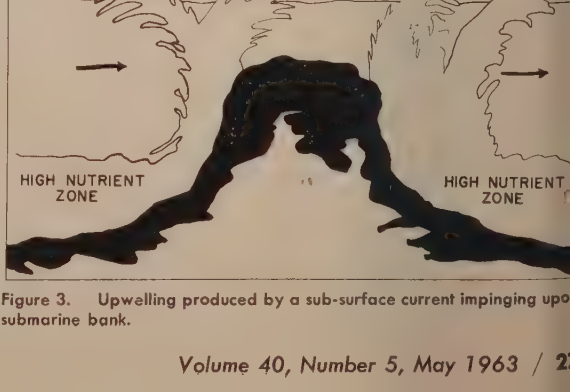
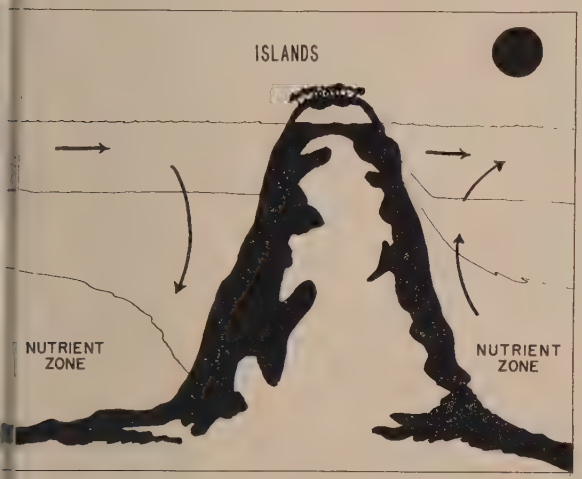
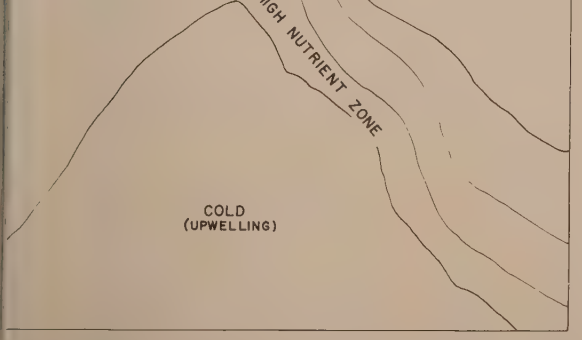



Figure 3. Upwelling produced by a sub-surface current impinging upo submarine bank.

cal eddies along the water column. The oscil-
y motion of the water in these eddies increases the
of diffusion of nutrient water upward against the
of gravity. However, this process is not nearly
ective as upwelling. A similar cyclical pattern of
lation is produced by convection cells (*10*).
e cells are formed by convection currents arising
a negative thermal gradient, or temperature
sion, where a warm water mass is occluded within
neath a cold water mass.
y condition which inhibits this vertical movement
ater is called stability (*5*). Such a condition is
d by a positive density gradient (i.e., a rapid
ase in density with depth). The density gradient,
rn, is related to either a rapid decrease in tem-
ture with depth, or a rapid increase in salinity,
some cases a combination of these two effects.
ever, since this phenomenon is usually associated
a thermal gradient we call it the thermocline or
ntinuity layer. Since large expanses of the
n areas have a reasonably well developed thermo-
either briefly during the warm summer season in
perature zones, or throughout the year in tropical
ns, vertical transport is effectively retarded in
of the oceanic areas. The net effect then, is




e 4. Upwelling produced by a surface current impinging on an
d mass.




re 5. Upwelling produced by turbulence at the boundary between
water masses.

depletion of the nutrients by biological utilization in the euphotic zone of these areas and regeneration and accumulation of nutrients in the abyssal regions.

### Surface Distribution of Inorganic Phosphates

Let us now examine the distribution of inorganic phosphate in the surface waters along the north-south plane of the Pacific Ocean. In theory we will take an oceanographic cruise from the equator to the Aleutian Islands, beginning the expedition in our own island paradise of Hawaii, which lies at approximately 20 degrees north latitude. In the vicinity of Hawaii, in the immediate inshore and offshore waters, the island mass effect which has been discussed earlier is in operation. Phosphate values are generally higher and subject to fluctuations, the peaks of which usually coincide with the rainfall peaks during the winter season. However, as we leave the influence of the Hawaiian Archipelago and proceed northward toward the Aleutians, the surface phosphate concentration rapidly decreases and we find ourselves in a phosphate poor region where the concentration remains relatively constant at 0.1 to 0.3 microgram atoms per liter. At approximately 30 degrees north latitude we enter a positive phosphate gradient where each change in our northerly progress is accompanied by a corresponding increase in the concentration of surface phosphate. At about 30 to 45 degrees north, depending upon the season of the year we are struck by a tremendous change in the physical appearance of the water. The beautiful deep blue of the sub-tropical regions has given way to a murky gray-green color indicative of a heavy biological population. Chemical and physical analysis of the water reveals drastic changes in these properties. Phosphate has increased until it is now ranging from 1 to 1.5 microgram atoms per liter. Oxygen has increased and salinity has decreased. The temperature of the water is quite variable but generally much colder. There are several factors responsible for this remarkable change in the ocean water. One is the fact that we have crossed a front between two distinct water masses. Here the cold subarctic water mass converges with the warmer subtropical waters of the central Pacific. In addition we are now in a temperature zone where thermocline development weakens at the end of the summer season and is almost completely broken down by the storms that prevail in the area during the fall and winter season (*7*).

If we proceed due south from Hawaii to the equator we find that the phosphate poor region extends as far south as 5 degrees north latitude. As we pass 10 degrees north latitude we enter one of the strange marine desert areas which border the equatorial zone. Here the surface phosphate concentration is very low and the water itself appears to be almost completely devoid of plant or animal life. This paucity of marine life in the surface water is reflected in the chemistry of the bottom sediments.

Continuing on toward the equator, at about 5 degrees north latitude we again enter a positive phosphate gradient. And then in the neighborhood of 3 degrees north we again find all of the visual and analytical evidence of strong upwelling of nutrient rich water and its highly productive biological population.

This should come as a surprise, because in this torrid tropical zone we could reasonably expect to find a well-developed thermocline existing throughout the year. However, other factors have entered into the picture. As a result of the combined effects of the trade winds and the rotation of the earth upon its axis, the action and reaction of the current systems from both hemispheres come to a focus along the equatorial belt. The interplay of these hemispheric forces promotes the upwelling of deep nutrient rich water into the euphotic zone.

We should keep in mind that we have been discussing the typical pattern of the distribution of surface phosphate in the Pacific Ocean and that there are frequently temporary and localized deviations from this pattern. For example, ships often pass through patches of discolored water which are called "plankton blooms." These blooms may reflect an unexpected and oftentimes inexplicable enrichment of the surface water. They are often followed by a depletion of the nutrient responsible and a subsequent disappearance of the phenomenon.

From these observations we see that the surface concentration of inorganic phosphate is primarily determined by two factors—the rate of biological consumption and the rate of physical replenishment. Note also that phosphate concentration may be a limiting factor regulating the size of the bio-mass. Let us now examine the distribution of surface oxygen in these same waters.

### Surface Distribution of Oxygen

Normally all surface water is supersaturated with oxygen as a result of wind and wave turbulence at the air-water interface, often in combination with a diurnal photosynthetic enrichment. The surface oxygen concentration is at a minimal value in the tropical waters of the equatorial belt. Each change in northerly progress from this boundary is associated with a corresponding increase in the concentration of surface oxygen. In the latitudes of Hawaii the concentration value is approximately 5 ml per liter, and we will notice that there is no predictable difference between the concentrations in inshore and extreme offshore waters as we had in the case of phosphate. We now know that the concentration of dissolved oxygen on the surface is affected by many more variables than phosphate. For example, oxygen values are a result of the interaction of biological consumption, biological production, turbulence, temperature, and salinity (*14*). Surface oxygen is not normally a limiting factor to biological growth as is frequently the case with phosphate. However, there are rough correlations between oxygen and phosphate concentrations on the surface as well as at specific points down the water column. For example, a heavy phytoplankton bloom resulting from phosphate enrichment will probably be associated with a significant increase in the degree of supersaturation.

### Vertical Distribution of Nutrients

In Figure 6 we have vertical profiles of the oxygen and phosphate concentration plotted against the depth in meters. We note the general inverse relationship between the concentrations of the two substances. An increase in phosphate is associated with a decrease in oxygen, and the prominent features of one curve are replicated on the other although not necessarily at exactly the same depth. Observing the oxygen curve in detail, we note that the concentration is a high 5 ml per liter at the surface but increases to a maximum at about 50 m. From this point downward a gradual but continuous depletion of oxygen is observed which is markedly accelerated at a depth of 500 m. Finally at 1200 m a minimal value is reached beyond which the concentration gradually increases. Extrapolation of this curve would show the oxygen concentration increasing in the deep abyssal waters until it might equal or exceed the surface value.

Phosphate on the other hand is a low 0.2 microgram atoms per liter on the surface and diminishes even further immediately below. Beneath this point the concentration increases in direct opposition to that of oxygen until the abyssal maximum is reached. Extrapolation of the phosphate curve would show relatively small fluctuations about this maximal value.

The most interesting portions of these profiles are the significant maxima and minima occurring in both the euphotic zone and the upper abyssal zone. These features are commonly found in many oceanic water masses. At one time these apparent anomalies were a complete mystery. However, we can now definitely explain the euphotic zone anomalies and even reproduce them on a laboratory scale. It seems that ultraviolet light has a detrimental effect on the photosynthetic process, and in the uppermost layer of the water the intensity of ultraviolet radiation is great enough to

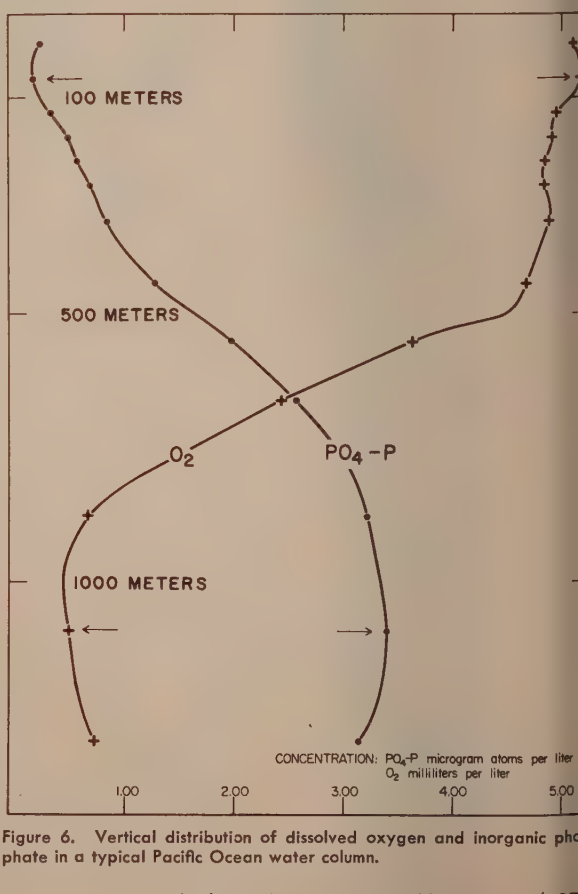



Figure 6. Vertical distribution of dissolved oxygen and inorganic phosphate in a typical Pacific Ocean water column.

bit this process. After traversing just a few meters he water column this radiation is reduced to the t that photosynthesis proceeds at its maximum , thus accounting for the sub-surface phosphate imum and oxygen maximum.

he abyssal phenomenon is not as readily explained. s indirectly related to biological activity, but may be associated with a physical factor. Application he principles of physics indicates that whenever a er mass is flowing over and in opposition to another s, vertical exchange between the two water masses acilitated and if the oxygen renewal exceeds the sumption rate in one mass (and it does) then mini- n oxygen values could be expected to coincide n the current boundary. The mathematicians e come to the assistance of the oceanographer evolved a system of equations to support this ory (*12*).

We should now consider the phenomenon of oxygen chment in abyssal waters. Oxygen concentration urface waters is highest in the frigid polar regions of earth's hydrosphere, reaching values in excess of nl per liter. Some of this polar water will inevitably verge on warmer water masses from lower latitudes. a result of the greater density of this extremely l water it will tend to sink down through the warmer ers into the abyssal depths, carrying along its rich ply of dissolved oxygen. Since biological activity mited at these extreme depths the oxygen concentra- n remains high. Now there is no doubt but that s process is continuously taking place and extracting ygen from the polar atmosphere and transporting it vn into the depths of the sea. The obvious con- sion resulting from this knowledge is that the hydro- ere and the atmosphere are in a state of gaseous uilibrium, the primary source of oxygen being the nosphere. However, Dr. A. C. Redfield of Woods le Oceanographic Institute has in recent years (*13*) roduced a rather startling new theory which con- ers the above described phenomenon to be only one all phase of a tremendous oxygen cycle in which sea itself is the primary generator of our atmospheric ygen supply. The point of origin of this cycle is at bottom of the sea where chemosynthetic sulfate cteria, under anaerobic conditions are extracting scent oxygen to be utilized in their metabolism and urning soluble combined oxygen to the water in the m of inorganic carbonates. These carbonates pro- le an immense oxygen reservoir, a portion of which is nsported to the photosynthetic zone through the ocesses of upwelling and diffusion. The carbonate terial is then utilized by phytoplankton and ele- ental oxygen released via the photosynthetic process. Diffusion of the oxygen into the atmosphere and back again now proceeds in accordance with the principles of chemical and physical equilibria.

Another phenomenon may affect the oxygen concentration in the abyssal regions. Whenever abyssal water masses are trapped within deep oceanic basins, as in the Black Sea, deep circulation may be completely stopped. Under these conditions the dissolved oxygen supply may be quantitatively depleted, followed by the establishment of anaerobic biological population. Significant concentrations of dissolved hydrogen sulfide will then appear in the water column in lieu of the normal oxygen supply.

## Summary

We have examined some of the most important mechanisms involved in the vertical transport of water. We have studied geographical and vertical distributions of some representative nutrient materials in one of our principal ocean areas, and finally we have considered the relationship between the concentrations of these substances and the biological productivity of any given water mass. All of these items are dynamic variables in the gross aspect of the earth's hydrosphere, and their quantitative values fluctuate in response to both random and periodic changes in the total environment.

## Acknowledgments

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Species Synopsis No. 22
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(Distribution restricted)



From Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No. 6, Vol. 2, P. 695-748. 1963.

# SYNOPSIS OF BIOLOGICAL DATA ON SKIPJACK Katsuwonus pelamis (Linnaeus) 1758 (PACIFIC OCEAN)

## Exposé synoptique sur la biologie du bonite à ventre rayé Katsuwonus pelamis (Linnaeus) 1758 (Océan Pacifique)

## Sinopsis sobre la biología del bonito de vientre rayado Katsuwonus pelamis (Linnaeus) 1758 (Océano Pacífico)

Prepared by
KENNETH D. WALDRON
U.S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

FISHERIES DIVISION, BIOLOGY BRANCH
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1963

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# 1 IDENTITY

## 1.1 Taxonomy

### 1.1.1 Definition (after Schultz, et al, 1960)

Phylum CHORDATA
Subphylum Craniata
Superclass Gnathostomata
Class Osteichthys
Subclass Teleostomi
Superorder Teleosteica
Order Percomorphida
Suborder Scombrina
Family Scombridae
Genus Katsuwonus
Species pelamis

Some of the larger taxa under which skipjack have been listed are shown in Table I. The tendency over the past few decades has been to set the tuna apart from other scombroids, and further to set up monotypic genera. Within recent years this tendency appears to be changing to one of re-including tuna in the family Scombridae and doing away with some of the monotypic genera. Under this system it is likely that skipjack will be included in the genus Euthynnus.

### 1.1.2 Description

- Genus Katsuwonus

"Body robust, naked outside the corselet; maxillary not concealed by preorbital; teeth present in jaws only; dorsal fins with only a short space between them, the anterior spines of the first fin very high, decreasing rapidly in length; second dorsal and anal each followed by 7 or 8 finlets; pectoral not very long, placed at or near level of eye, with about 26 or 27 rays." (Hildebrand, 1946). The foregoing statement is applicable to mature adults of the genus.

- Species Katsuwonus pelamis (Linnaeus) (Fig. 1)

"Head 3.0 to 3.2; depth 3.8 to 4.1; D. XIV or XV - I, 13 or 14 - VIII; A. II, 12 or 13 - VII; P. 26 or 27; vertebrae 40 (one specimen dissected). [Note: Both Kishinouye, 1923 and Godsil and Byers, 1944 give the number of vertebrae as 41.]

"Body robust, its greatest thickness about two-thirds its depth, tapering strongly posteriorly; caudal peduncle slender, depressed, with a strong lateral keel, its depth 14 to 15.3 in head, head somewhat compressed, convex above; snout long, pointed, 3.3 to 3.7 in head; eye moderate, round, 5.7 to 6.1; interorbital 3.7 to 4.0; mouth slightly oblique, terminal; maxillary reaching nearly or quite opposite middle of eye, 2.6 to 2.8 in head; teeth in jaw in single series, short and rather stocky; gill rakers long, slender, about four-fifths length

Table I

Classification of skipjack according to different authors

| Group | Authority | | | | |
|---|---|---|---|---|---|
| | Regan 1909a, b | Kishinouye 1923 | Jordan, Evermann and Clark 1930 | Berg 1940 | Schultz et al. 1960 |
| PHYLUM | - | - | - | - | Chordata |
| SUBPHYLUM | - | - | - | - | Craniata |
| CLASS | Pisces | - | Pisces | Teleostomi | Osteichthys |
| SUBCLASS | Neopterygii | - | Actinopteri | Actinopterygii | Teleostomi |
| SUPERORDER | - | - | Acanthopterygii | - | Teleosteica |
| ORDER | Percomorphi | Plecostei | Percomorphi | Thunniformes | Percomorphida |
| SUBORDER | Scombroidei | - | Rhegnopteri | - | Scombrina |
| SERIES, SECTION DIVISION | Scombriformes | - | Scombriformes | - | |
| FAMILY | Scombridae | Katsuwonidae | Katsuwonidae | Thunnidae | Scombridae |
| SUBFAMILY | - | - | - | Auxidini | - |
| GENUS | - | Katsuwonus | Katsuwonus | Katsuwonus | Katsuwonus |
| SPECIES | - | pelamis | vagans | - | pelamis |

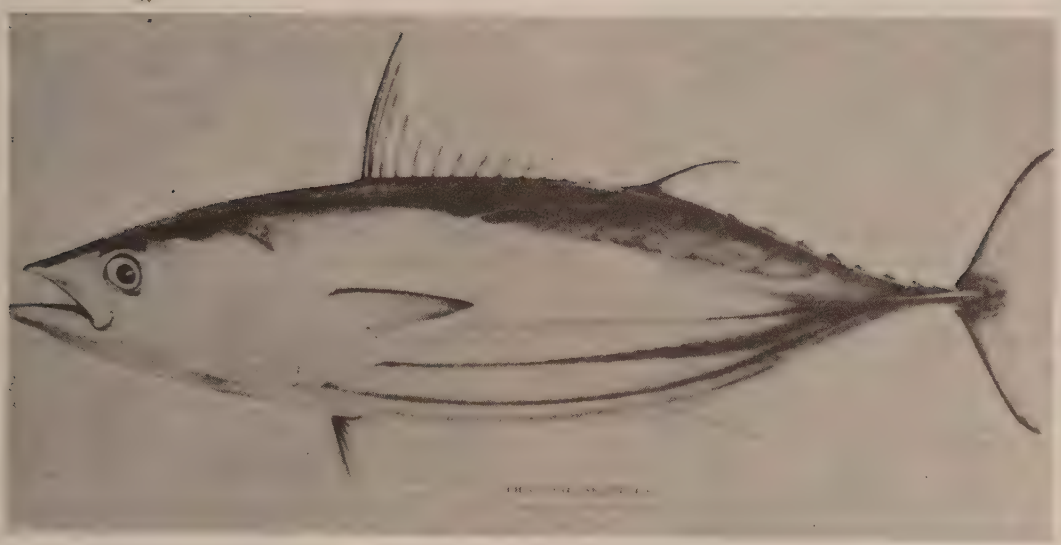

**Fig. 1** Lateral view of an adult skipjack, Katsuwonus pelamis (Linnaeus) (from Walford, 1937)

of eye, 36 to 40 on lower and 15 or 16 (counted in only 3 specimens) on upper limb of first arch; lateral line missing anteriorly, curved downward at midlength, attaining a midlateral position under about the first dorsal finlet, straight from thence to caudal keel; scales present anteriorly in region of pectoral, extending on back to or beyond origin of first dorsal, reduced scales in lateral line, and a pointed area of scales extending about an eye's diameter beyond tip of pectoral fin; first dorsal composed of slender spines, the anterior ones long, posterior ones short, scarcely extending above dorsal groove, the first one 1.8 to 2.0 in head, origin of fin a little behind insertion of pectoral, its distance from tip of snout 2.6 to 2.9 in length; second dorsal somewhat elevated anteriorly, with deeply concave margin, the posterior rays being very short, its origin about equidistant from origin of first dorsal and base of next to last dorsal finlet; anal similar to second dorsal, its origin a little in advance of vertical from base of last ray of second dorsal; ventral somewhat shorter than pectoral, inserted slightly posterior to pectoral, its distance from tip of mandible 2.7 to 2.9 in length; pectoral moderately pointed, 1.9 to 2.1 in head.

"Color very dark blue above, with metallic reflections; silvery below; lower part of head, chest, and area around ventral fins dirty white; lower half of side with two to four dark longitudinal strips; spines of first dorsal dusky, anterior margin of first spine and membranes pale or white; second dorsal, dorsal and anal finlets, caudal, anal, and pectoral all more or less dusky; pectoral much darker on inner side than outside, the upper rays generally silvery; ventral fins white on outside, inner side dusky; inside of mouth largely dusky." (Hildebrand, 1946). In life, and in some preserved specimens, light vertical bars are evident along the sides.

Anatomical descriptions of the species and genus may be found in Kishinouye (1923), Godsil and Byers (1944), Schultz et al (1960).

Kishinouye (1923, p. 452) states, "The cutaneous circulatory system is unique. A pair of cutaneous arteries branch just behind the insertion of the pharyngeal muscles as in the tunnies and other bonitos; but passing through the kidneys the arteries turn outward and forward, instead of turning more or less backward as in the other plecostean fishes. Each artery reaching to the myotome of the first rib is divided into two arteries, epaxial and hypaxial. The epaxial artery runs below the first rib, while the hypaxial artery runs above the rib. These two arteries, are nearly equally developed, and are separated from each other at a distance of 6-8 times the breadth of the blood-vessels. These arteries do not form a loop at the caudal region. The cutaneous artery and cutaneous vein lie in juxtaposition, nearly flat at the surface of the body. Arterioles and venules connected with these cutaneous canals run in opposite directions, along the surface of the body and they are not so numerous as in the tunnies. The rod of the vascular plexus in the haemal canal is called kurochiai by fishermen, and it is thicker than the diameter of the vertebral column."

The spinal column (Fig. 2) differs sufficiently from that of other fishes to be worthy of comment. Godsil and Byers (1944) state "The spinal column is extremely complex in this species. In the posterior half of the precaudal, and the anterior part of the caudal region, haemopophyses arise at both ends of each vertebra, with the anterior haemopophyses of one vertebra articulating with the posterior haemopophyses of the preceding vertebra. These haemopophyses project far below the spinal column and alternate with the longer haemal spines described below. An osseous bridge roughly parallel with the spinal column unites the anterior and posterior haemopophyses of each vertebra. Viewing the spinal column laterally, the bridge and the circular opening it forms may be easily seen. A branch arises from each bridge and extends downward to unite in the median line with its fellow from the opposite side. This forms the haemal arch from the tip of which a single haemal spine continues ventralward. This complex basketwork occurs only in the skipjack."

The skipjack lacks an air bladder.

Some of the organs not mentioned by Godsil and Byers (1944) or not described in detail by Kishinouye (1923) have been described by other authors. Among these descriptions are those of Rivas (1953) and Rasquin (1958) concerning

the pineal region; Uchihashi (1953) on the brain as related to ecology; Hanyu (1959) on certain structures of the eye; and Suyehiro (1941, 1942, 1950) on the pituitary body, the Islets of Langerhans, and the digestive system (it might be noted that this author erred in ascribing an air bladder to skipjack).

## 1.2 Nomenclature

### 1.2.1 Valid scientific name

Katsuwonus pelamis (Linnaeus, 1758) has been widely accepted as the scientific name of skipjack since it was first proposed in 1915 by Kishinouye, although at that time he used the spelling "pelamys". The present tendency appears to be towards replacing Katsuwonus with Euthynnus, retaining the specific name pelamis.

### 1.2.2 Other scientific names ascribed to this species

The following list of names, taken mainly from Rosa (1950), is arranged in alphabetical rather than chronological order. Each name is followed by one of the early authors to use the combination.

| | |
|---|---|
| Euthynnus pelamis | Tanaka, 1912 |
| Euthynnus (Katsuwonus) pelamis | Fraser-Brunner, 1950 |
| Euthynnus pelamys | Jordan and Gilbert, 1882 |
| Gymnosarda pelamis | Dresslar and Fesler, 1889 |
| Gymnosarda pelamys | Barnard, 1925 |
| Katsuwonis pelamis | Herre, 1933 |
| Katsuwonus pelamis | Kishinouye, 1923 |
| Katsuwonus pelamys | Kishinouye, 1915 |
| Katsuwonus vagans | Jordan, Evermann, and Clark, 1930 |
| Orcynus pelamis | Goode and Bean, 1879 |
| Pelamys pelamys | Bleeker, 1865 |
| Pelamys thynnus | Jenkins, 1925 |
| Scomber pelamides | Lacépède, 1802 |
| Scomber pelamis | Linnaeus, 1758 |
| Scomber pelamys | Bloch and Schneider, 1801 |
| Thynnus pelamis | Hoek, 1914 |
| Thynnus pelamys | Cuvier and Valenciennes, 1831 |
| Thynnus vagans | Lesson, 1830 |

1.2.3 Standard common names, vernacular names

The following list of common names and vernacular names, the latter in parentheses, and the countries in which they are used was taken from Rosa (1950). Other common names not included in the list, refer to skipjack of a particular size, or to aggregations of skipjack as opposed to individual fish.

1.3 General variability

1.3.1 Subspecific fragmentation (races, varieties, hybrids)

It is generally recognized that there is but one world-wide species of skipjack, which cannot be differentiated into subspecies. Working with Pacific specimens, Hennemuth (1959) stated that, "The statistical analysis indicates then, that the commercially available stocks of skipjack inhabiting the various fishing areas within the Eastern Pacific for which data are available represent semi-independent populations of fish, and the stocks of the Eastern and Central Pacific also appear to be at least semi-independent."

- Varieties

There are no records of varieties of skipjack.

- Meristic counts

Table II presents meristic counts listed in two publications.

1.3.2 Genetic data (chromosome number, protein specificity)

Little data concerning the genetics of skipjack exist in the literature, and what can be found are of recent origin. There are no data concerning the chromosome number of skipjack.

Considerable work is being done at present (1962) concerning the serological relations between skipjack from the same and from

COMMON NAMES OF SKIPJACK FOR PACIFIC COUNTRIES (FROM ROSA, 1950)

| | |
|---|---|
| Australia | Striped tuna |
| Canada | Skipjack (Oceanic bonito) |
| Chile | Atún (Cachurreta, Cachureta, Cachorreta, Barrilete) |
| China | Tow chung (Chien) |
| Hawaiian Is. | Skipjack (Ocean bonito, Little tunny, Striped tuna, Aku, Aku kinau) |
| Indonesia | Bonito |
| Japan | Katuwo (Katsuwo, Katsuo, Magatsuwo, Mandagagatsuwo) |
| Mexico | Barrilete |
| New Guinea (Neth.) | Tjakalang |
| New Zealand | Bonito |
| Peru | Barrilete |
| Philippines | Skipjack (Striped tuna, Gulyasan, Pundahan, Bankulis, Oceanic bonito, Sobad, Bonito, Palawayan) |
| Polynesia (except Tahiti and Hawaii) | Atu |
| Tahiti | Auhopu |
| United States | Skipjack (Arctic bonito, Oceanic skipjack, Striped tuna, Watermelon, Victor fish, Striped bonito, Oceanic bonito, Skippy, Ocean bonito) |

Table II

Meristic characters of skipjack from the Pacific

| | Japan (Godsil and Byers, 1944) | Japan (Nakamura Res. Stf. 1949) | Hawaii (Godsil and Byers, 1944) | Eastern Pacific (Godsil and Byers, 1944) |
|---|---|---|---|---|
| 1st Dorsal | 15-16 | 14-17 | 15-16 | 15-16 |
| 2nd Dorsal | 14-15 | 13-15 | 14-16 | 14-15 |
| D. Finlets | 8 | 8-10 | 7-8 | 7-8 |
| Anal | 14-15 | 13-15 | 15 | 14-16 |
| Anal Finlets | 7 | 6-9 | 7 | 6-8 |
| Pectoral | - | 24-32 | - | - |
| Ventral | - | - | - | - |
| Gill Rakers | 16-20+ | | 19-20+ | 18-22+ |
| Upper + Lower | 36-41 | | 37-42 | 35-43 |
| Total | | 44-61 | | |
| Vertebrae | 41 | | 41 | 41 |

different locations. Most of this work is being done in the Pacific.

Cushing (1952) in one of his early studies of skipjack blood found that it contained an agglutinin specific for the human type B substance. Later he found (Cushing, 1956) that within a group of ten skipjack taken from one location near the Hawaiian Is. four different categories based on blood factors were discernible. Group one had a strong affinity for antibodies of rabbit antiserums prepared against the blood of yellowfin tuna, albacore, skipjack, and white croakers. Group two contained antigens with strong affinities for the "natural" antibodies of "normal" sera (human, bovine, sheep). Group three contained both of the above antigens, while group four contained neither.

Recently Sprague (1961) and Sprague and Nakashima (1961) reported finding differences in the agglutination by phytoagglutinins of blood of skipjack from different localities in the Pacific. They used saline extracts of the seeds from various legumes to define four blood factors which were named A-positive, D-positive, Be, and Bf, which could be detected by extracts of seeds of Glycine max, Phaseolus vulgaris, Virgilia divaricata, and Caragana arborescens respectively. Working with reagents which detect A-positive, C-positive, and Be-positive bloods it was possible to differentiate between groups of skipjack from Rangiroa, from the Marquesas Is., and from the Hawaii-Johnston-Christmas Is. area.

Schaefer (1961a) reported the discovery of possibly two blood-type systems among skipjack from the eastern Pacific through the use of a battery of phytohemagglutinins. He expressed the belief that at least one of the systems would be suitable for the study of skipjack populations within the area of the eastern Pacific fishery.

Matsumoto (1960) reported on the differentiation of tuna species by means of paper chromatography and found that skipjack could be separated from yellowfin, bigeye, albacore, and two species of frigate mackerel on the basis of two-dimensional chromatograms. Fig. 3 shows the two-dimensional chromatograms for adult and larval skipjack from central Pacific waters.

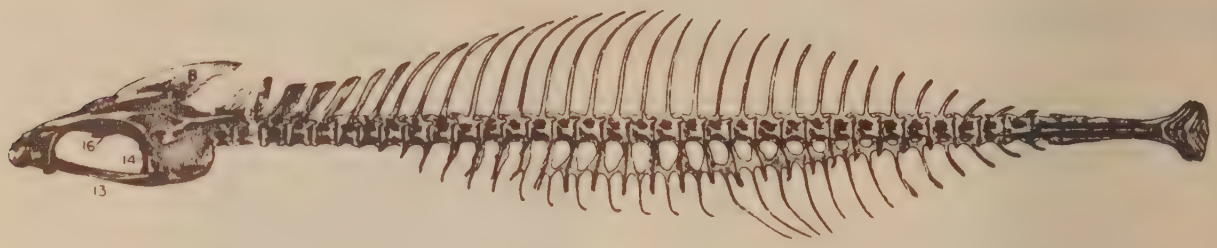


Fig. 2 Cranium and spinal column of an adult skipjack (after Godsil and Byers, 1944)

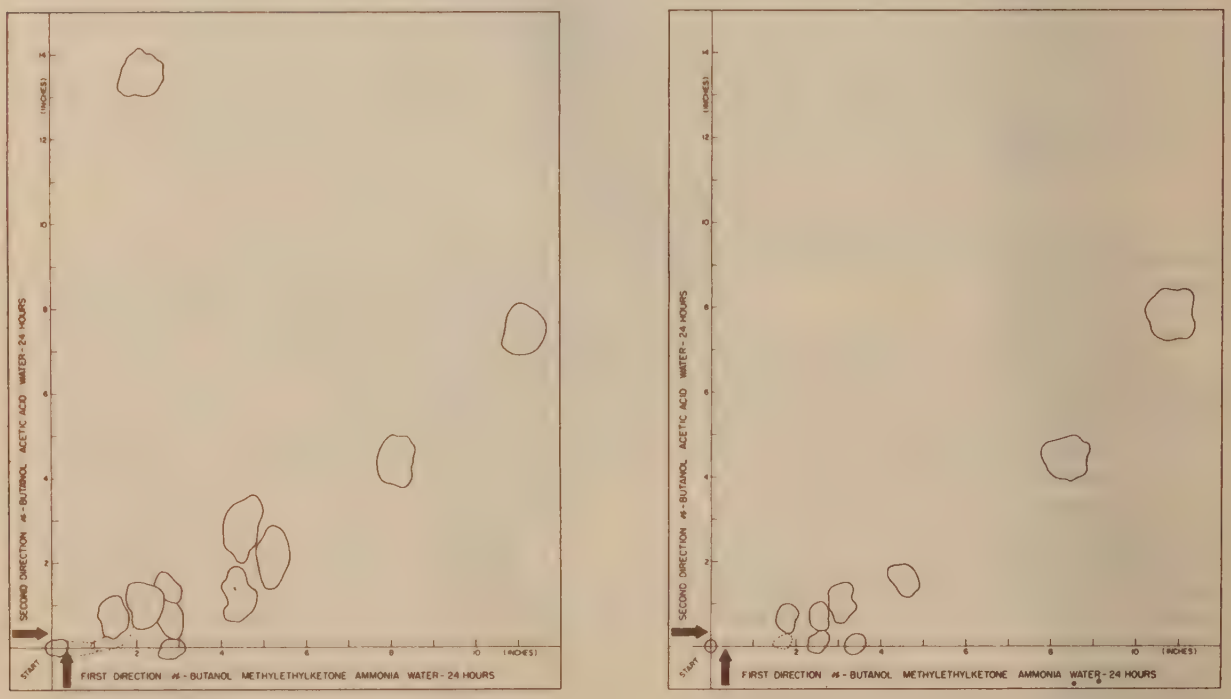
SECOND DIRECTION #-BUTANOL ACETIC ACID WATER-24 HOURS
(INCHES)
START
FIRST DIRECTION #-BUTANOL METHYLETHYLKETONE AMMONIA WATER-24 HOURS
SECOND DIRECTION #-BUTANOL ACETIC ACID WATER-24 HOURS
(INCHES)
START
FIRST DIRECTION #-BUTANOL METHYLETHYLKETONE AMMONIA WATER-24 HOURS

Fig. 3 Two dimensional chromatograms for adult (left panel) and larval skipjack (right panel)(from Matsumoto, 1960)

## 2 DISTRIBUTION

### 2.1 Delimitation of the total area of distribution and ecological characterization of this area (Fig. 4)

Rosa (1950) gives the following distribution for skipjack in the Pacific Ocean.

"South Pacific Ocean - Coast of Ecuador including Galapagos Is., off the coast of Peru approaching it during certain periods of the year in certain areas, coast of Chile as far south as Valparaiso, coast of Australia from New Guinea to St. Helens in northeast Tasmania, coast of New Zealand.

"North Pacific Ocean - Seldom found on the coast of Canada on Vancouver Is., and on the coast of the United States north of Point Conception in California, common from this point to Mexico, entire coast of Mexico, including the Gulf of California, entire coast of Central America; Marshall, Caroline, and Palau Is., Philippines, Formosa Is., Ryukyu Is., Pacific coast of Japan as far north as off the south coast of Hokkaido, Kurile Is., Bonin and Marianas Is., occasionally found in the Japan Sea as far as the coast of U.S.S.R. during the summer."

Skipjack are also taken throughout the general Pacific areas of Polynesia including Hawaii, Melanesia, and Micronesia. In the mid-North Pacific skipjack have been taken as far north as latitude 43° N.

The area described above and shown in Fig. 4 is characterized in general by temperatures at the surface of 15° C or greater and lies roughly between latitudes 40° N and 40° S. Where skipjack are found outside these limits may indicate the presence of a tongue of warmer water.

Blackburn (1961) has pointed out that skipjack may avoid areas with temperatures above 28° C.

- Vertical distribution

While no direct evidence is available it is generally considered that skipjack inhabit only the upper one or two hundred meters of the surface waters.

### 2.2 Differential distribution

#### 2.2.1 Areas occupied by eggs, larvae, and other young stages: annual variations in these patterns and seasonal variations for stages persisting over two or more seasons. Areas occupied by adult stages: seasonal and annual variations of these.

- Eggs

The distribution of skipjack eggs has not been described, because it has not been possible to differentiate skipjack eggs from those of other tunas.

- Yolk sac stage

This developmental stage is so rare in collections that it is not possible to define the distribution. With the possible exception of the vertical distribution, it is probably found in the same areas as the non-yolk sac stages.

- Larval stages

Larval skipjack have been found in all the major oceans of the world. In the Pacific, Kishinouye (1926) collected larvae from the Ryukyu Is. area, and Yabe (1955) reported on larvae collected in the waters of the Caroline and Marianas Is. as well as from the Ryukyu Is. Matsumoto (1958) and Strasburg (1960) reported on larvae collected in the central Pacific, both north and south of the Equator, Wade (1950) reported on older larvae from Philippine waters, Schaefer and Marr (1948) reported the capture of large larvae from the Marshall Is., and Schaefer (1960) reported the capture of larvae and juveniles in the eastern Pacific.

Skipjack larvae have been taken within 600 feet (= ca. 185 m) of shore in the Hawaiian Is. (Strasburg, 1960), as well as in the open ocean far from land.

The north-south distribution of larvae appears to be somewhat more restricted than does that of the adults. Matsumoto (1958) reported the capture of larvae to latitude 25° N, and Strasburg (1960) records

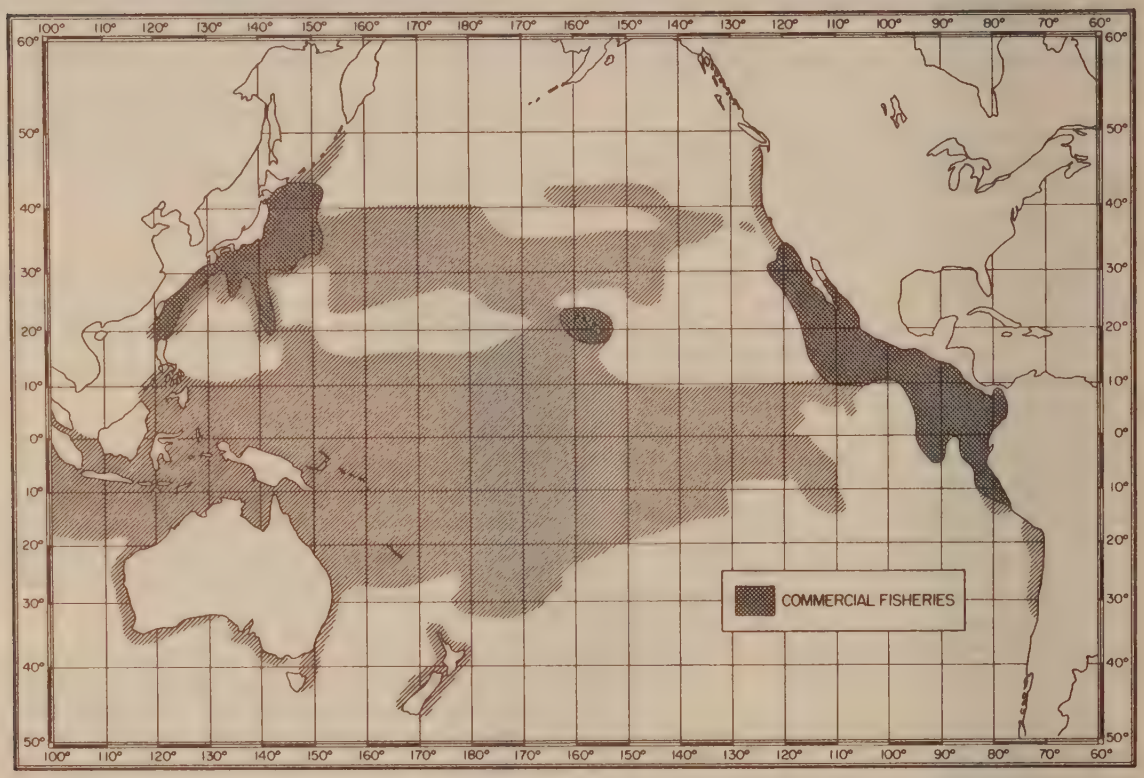


Fig. 4 Distribution of adult skipjack in the Pacific Ocean, and location of the commercial fisheries in the western, central, and eastern Pacific (Brock, 1959)

larvae to latitude 18° S in the mid-Pacific. However, this was also the limit of sampling, and so may represent an artifact of sampling rather than the limit of distribution of the larvae. In the western Pacific Yabe (1955) reported skipjack larvae from about latitude 33° N, and Brock (1959) shows larvae occurring off the Australian east coast at about latitude 33° S. Fig. 5 shows locations in the Pacific from which larvae have been collected.

With respect to vertical distribution, Strasburg (1960) has shown that in the Pacific, larval skipjack (specimens less than 15 mm length) are very rarely taken below 140 m depth. He further stated that 15° C appeared to be a limiting temperature, and in the one exception, when larvae were collected below 140 m, a tongue of warm water extended below this depth.

- Juveniles

By the time the young reach a length of about 20 mm they have acquired many of the adult characteristics, although the body form is somewhat different. They may be considered juveniles until they have acquired the coloration and body form of the adult, this occurring at a length of about 200 to 250 mm.

Juvenile skipjack have been reported from much the same locations as have the larvae and the adults. Up to a length of about 45 mm they have been collected under night lights with dip nets. Above that size most of the specimens collected have come from the stomachs of larger fish, mainly other tunas and spearfishes.

Most of the published records are from the Pacific area, and Table III lists collections of juvenile skipjack up to 1951. Chapman (1946) reported schools of "8 -10 inch skipjack" in the Solomons Is. area, and skipjack of less than 250-mm size have been observed in Hawaiian waters.

Table III

Records of the capture of juvenile skipjack (Shimada, 1951)

| Author and date of publication | Locality of capture or Latitude Longitude | Length of specimens in mm | Number of specimens | Date of capture |
|---|---|---|---|---|
| Kishinouye, 1923 | Ryukyu Is. (Okinawa) | 210 | 1 | Aug. 1916 |
| Kishinouye, 1924 | do. | 105, 125 | 2 | July 1923 |
| Do. | do. | 120, 153 | 2 | June 1924 |
| Do. | 28°10'N 129°15'E | 58 | 1 | May 1924 |
| Do. | 29°51'N 129°52'E | 60, 80 | 2 | May 1924 |
| Do. | 29°47'N 129°25'E | 63, 83, 85 | 3 | May 1924 |
| Kishinouye, 1926 | 29°47'N 129°25'E | 26 | 1 | April 1924 |
| Do. | Ryukyu Is. (Okinawa) | 210 | 1 | Aug. 1923 |
| Do. | do. | 100-140 | 3 | June 1924 |
| Inanami, 1942 | Truk Is. | 198 | 1 | April 1939 |
| Do. | do. | 45 | 1 | May 1940 |
| Schaefer and Marr, 1948 | 9°22.5'N 85°47.5'W | 21 | 1 | Jan. 1947 |
| Do. | 9°10'N 85°20'W | 44 | 1 | Mar. 1947 |
| Marr, 1948 | Bikini Atoll | 45, 50 | 2 | July 1947 |
| Wade, 1950 | 6°37.2'N 121°31'E | 13-27 | 6 | July 1948 |
| Eckles, 1949 | 20°30'N 158°45'W. | 113-118 | 6 | July 1948 |
| Do. | 19°33'N 156°00'W | 183 | 1 | Sept. 1948 |
| Shimada, 1951 | 3°50.5'S 171°48.5'W | 35, 48 | 2 | July 1950 |
| Do. | 4°30' S 172°11' W | 20, 22, 36 | 3 | Aug. 1950 |

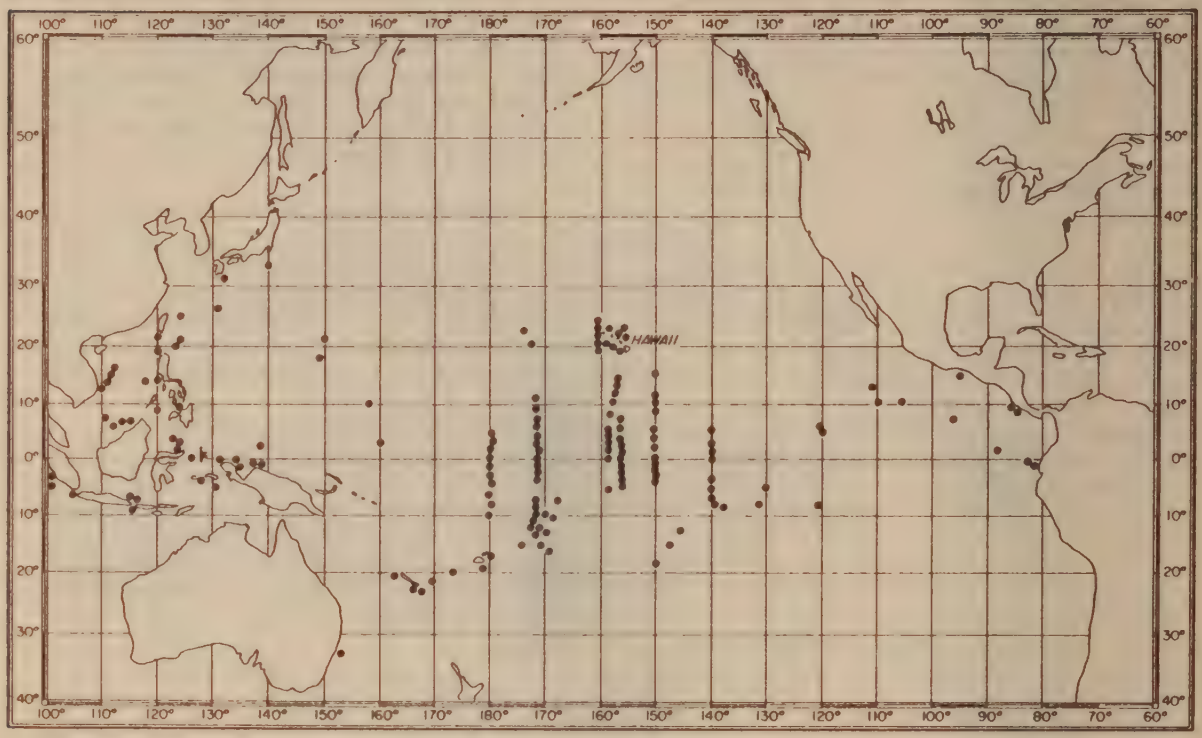


Fig. 5 Distribution of larval skipjack in the Pacific Ocean (Brock, 1959; Yabe, 1955; Schaefer, 1960)

With the exception of the eastern Pacific specimens (Schaefer and Marr, 1948) all of the juveniles were collected between April and September. The eastern Pacific specimens were collected in January and March. Suda (1953) reported young skipjack most numerous in stomachs of large predators during June and August in the Bonin-Minamitorishima area south of Japan.

- Adults

At about 220 mm skipjack begin to be taken in commercial fisheries and may be considered as sexually immature sub-adults.

## 3 BIONOMICS AND LIFE HISTORY

### 3.1 Reproduction

#### 3.1.1 Sexuality (hermaphroditism, heterosexuality, intersexuality)

The skipjack is normally heterosexual. There are a few recorded instances of hermaphroditism (Nakamura, 1935; Uchida, 1961). It is not known if these examples were functional hermaphrodites. In a specimen received at the Biological Laboratory, Honolulu, and described by Uchida (1961) the ovarian section contained ripe and resorbing ova, but the testicular portion showed no evidence of running milt.

#### 3.1.2 Maturity (age and size)

There is no definite information concerning the age at which skipjack mature, and this can be attributed to differences of opinion as to the age of skipjack in general. Brock (1954) used length frequencies occurring in commercial landings to age fish and with respect to maturity stated, "It therefore appears likely, considering also the information on age and rate of growth, that aku may mature at 1 year." Yabe (1954), following the aging method developed by Aikawa and Kato (1938), stated with respect to maturity that, "Providing that these represent the smallest mature fish, both male and female were age IV fish, according to the age determination of Dr. Aikawa." Ripe males 391 mm and spawned out females 407 mm in length have been reported by Marr (1948) from the Marshall Is. area. In Hawaiian waters Brock (1954) reported a ripe female 432 mm in length, and he also stated that the smallest fish with maturing ovaries were between 40 and 45 cm in length. Yabe (1954) reported the smallest skipjack with mature eggs measured 46.8 cm. Wade (1950) reported a ripe female only 340 mm in length from Philippine waters, although most of the ripe females which he reported were above 400 mm in length.

#### 3.1.3 Mating (monogamous, polygamous, promiscuous)

No information is available as to the mating behavior of skipjack. In view of their known schooling behavior it is reasonable to assume that mating is promiscuous.

#### 3.1.4 Fertilization (internal, external)

There are no publications describing fertilization of skipjack eggs, but since males lack any intromittent organ fertilization is probably external.

#### 3.1.5 Fecundity

- Relation of gonad size and egg number to body size and to age

Yabe (1954) found considerable variation in the number of eggs in skipjack of similar and different sizes. Table IV is modified from his table 6.

As can be seen from the table, skipjack differing in weight by only 0.7 kg may differ by over 700,000 in the number of ova (specimens 1 and 2). Both these fish were presumably the same age, either age group IV according to Aikawa and Kato (1938) or 1-year-olds according to Brock (1954).

Yoshida (MS) made ova counts on four skipjack from the Marquesas Is. area and found the ripening eggs numbered 0.1 million in a 43-cm and 2.0 million in a 75-cm skipjack.

Table IV

Estimated numbers of maturing ova in skipjack of different size

| Fish | | Ovaries | | Total number of eggs |
|---|---|---|---|---|
| Length (cm) | Weight (kg) | Weight (gm) | Maturity | |
| 46.8 | 2.55 | 106.5 | mature | 113,364 |
| 49.5 | 3.2 | 227 | mature | 856,180 |
| 54.5 | 4.5 | 119 | immature | 565,131 |
| 56.2 | 5.25 | 250 | mature | 609,730 |
| 61.0 | 5.96 | 148.9 | immature | 859,897 |

3.1.6 Spawning

- Spawning seasons (beginning, end, peak)

The literature contains a number of references to spawning seasons, most of which are based on the presence of young in collections or on the stage of gonad maturity in the adult fish. Table V lists some of the more recent estimates of spawning seasons, and the basis of the estimate, in the Pacific. It appears that in equatorial waters spawning occurs throughout the year, although there may be identifiable peak periods. At increasing distances from the Equator the season becomes progressively shorter and occurs during the summer months.

The presence of larval skipjack in plankton collections probably provides a more precise estimate of spawning seasons than does the presence of mature ovaries in the adults. Brock (1954), on the basis of gonad condition, placed the spawning season in Hawaiian waters between February and September, while Sherman and Brown (MS), working with larval collections from Hawaiian waters, have hypothesized that spawning activity peaks sharply in late spring and early summer, i.e., May to July.

Yabe (1954) states that in the western Pacific skipjack above 50 cm length show the greatest gonad development between May and June, while the smaller skipjack under 45 cm length show the greatest gonad development during June to August.

- Number of spawnings per year, frequency

There is no direct evidence as to the number of spawnings per year. Brock (1954) and Yoshida (MS) have hypothesized, on the basis of multiple modes in ova diameter frequency distributions that there is multiple spawning

- Spawning time of day

No information available nor does the literature contain any hypotheses concerning this aspect of spawning.

3.1.7 Spawning grounds

- Coastal (surface, vegetation, shore shoal, sand, shelter); bottom

No direct evidence exists as to the localized distribution of spawning. Larvae have been found in very close proximity to land, e.g. Strasburg (1960) reported larvae in Hawaiian waters collected within a few hundred yards of shore. However, spawning could have taken place at some distance offshore and the larvae have been carried inshore by currents.

Table V

Skipjack spawning periods in the Pacific Ocean

| Area | Author | Spawning period | Evidence 1/ |
|---|---|---|---|
| Central America | Schaefer and Marr, 1948 | January - March | Gonad; juveniles |
| Central America | Schaefer and Orange, 1956 | December - March | Gonadal |
| Revillagigedos | Schaefer and Orange, 1956 | Summer and Fall 2/ | Gonadal |
| Hawaiian waters | Brock, 1954 | February - September | Gonadal |
| Hawaiian waters | Sherman and Brown (MS) | May - July | Larvae |
| Central Equatorial Pac. | Matsumoto, 1958 | All months except April and December | Larvae |
| Marquesas-Society Is. | Yoshida (MS) | November to April | Gonadal and larvae |
| Marshall Is. | Marr, 1948 | April to August | Gonadal and juveniles |
| Philippine waters | Wade, 1951 | All year with peak September to April | Larvae |
| Japanese waters | Yao, 1955 | June - August | Gonadal |
| Japanese waters | Yabe, 1954 | May to August | Gonadal |

1/ Evidence: Gonadal = Presence of ripe or maturing ovaries in adults observed.
Juveniles = Juveniles collected.
Larvae = Larvae collected.

2/ Near the Revillagigedos summer and fall would be from July to December approximately.

- Oceanic (surface, bottom)

Again there is no direct evidence as to the exact location of spawning, but most of the larvae collected have been taken in plankton tows made at some distance from land. Because most of the larvae have been collected from the upper 200 m of the ocean (Strasburg, 1960), it might be assumed that spawning takes place no deeper than this. Further, fishermen have reported sighting spawning fish near the surface, however, the spawning activity was deduced from the behavior of the fish rather than from an actual observation of the spawning act.

3.1.8 Egg: structure, size, hatching type, parasites, and predators

Yoshida (MS) gives the following description of the ovarian eggs of skipjack: "Four rather distinct developmental stages were recognized and designated as 'early developing,' 'developing,' 'advanced', and 'ripe'. The early developing category includes ova which in the most primitive stage appear as simple transparent cells. The larger ova in this stage contain a relatively large nucleus. The mean diameter ranged from 0.16 to 0.33 mm. Ova in this category are present in all ovaries. The developing ova are completely opaque owing to the deposition of yolk granules. The mean diameter of these ova ranged from 0.37 mm to 0.66 mm. The advanced stage includes ova ranging in appearance from those which were still relatively opaque and containing a cluster of small oil droplets, to those which were semi-transparent and containing a well-developed, bright yellow oil globule. The mean diameter of these ova ranged from 0.49 mm to 0.74 mm." Yoshida goes on to describe the running ripe eggs of skipjack as, "They were almost perfectly spherical and transparent, with a distinct straw-colored oil globule. Fifty were measured. They ranged in diameter from 0.85 mm to 1.12 mm with a mean diameter of 0.96 mm. The oil globule measured about 0.14 mm in diameter."

Brock (1954) described running ripe skipjack ova as averaging 1.125 mm in diameter, spherical to slightly oval, with a single oil globule which was between 0.22 and 0.45 mm in diameter. Yabe (1954) gave the size of running ripe ova as 0.80 to 1.17 mm diameter (average 1.00 mm), with a single oil globule measuring 0.22 to 0.27 mm in diameter (average 0.23 mm).

No information is available concerning the embryonic development, hatching type, parasites, or predators of the skipjack egg.

## 3.2 Larval history

### 3.2.1 Account of embryonic and juvenile life (prelarva, larva, post larva, juvenile) (Fig. 6)

Accounts of the embryonic development of skipjack are lacking from the literature. The first distinguishable skipjack are in the post-yolk-sac stage at a length of about 3 mm (Kishinouye, 1926). Considering that the ripe ovarian egg is about 1.0 mm in diameter, the skipjack larvae must approach 3.0 mm in length at hatching. As Kishinouye himself points out, these 3.00 mm larvae must have been hatched very recently. The first specimens which Kishinouye (1926) identified positively as skipjack were 4 mm in length. He described this specimen as follows: "The head is greatly developed and about 10 large sharp teeth appear on each side of both jaws. The vomerine teeth are not yet developed. There are two spines on the surface of the preopercle and five or six spines on its edge. The spines on the posterior edge are long and stout, with the one at the angle being the longest. There is only a shallow round depression at the location of the nasal cavity. The distribution of melanophores is roughly the same as in the specimens described above [Note: these refer to the 3 mm specimens], but one notable difference is the presence of a large melanophore slightly anterior and ventral to the caudal peduncle. There are also many melanophores around the anterior end of the spinal cord, and the tip of the mandible is blackish. The posterior end of the spinal cord is perfectly straight. It is difficult to tell the number of myotomes because they are not yet fully developed at the posterior end of the body, but there appear to be forty-one of them."

Wade (1951), Yabe (1955), and Matsumoto (1958) provide descriptions of larval skipjack less than 15 mm in length collected from the Pacific area. Two characteristics which appear in all of the descriptions are the large size of the head, and the presence on the mid-ventral portion of the caudal peduncle of a melanophore or group of melanophores. These two characteristics, together with the presence of 41 myomeres, appear to distinguish skipjack larvae of about 4 to 5 mm length. Matsumoto (1958) gives the following distinguishing characteristics of skipjack larvae between 3.7 and 14.5 mm in length (Table VI).

Kishinouye (1926), Marr (1948), Schaefer and Marr (1948), Wade (1950, 1951), and Shimada (1951) describe the juvenile skipjack, generally those above 15 mm in length. The most reliable characteristic used in identifying specimens above this size appears to be the presence of 41 vertebrae and the complex trellis or basket-work formed by the haemal arches. In stained specimens these are visible in juveniles as small as 27 mm length (Wade, 1950), although the haemal arches are not completely closed.

Preopercular spines, which have been used in describing the larvae become buried in bone by the time juveniles reach 40 mm (Schaefer and Marr, 1948), while the palatine teeth do not become overgrown until about 60-75 mm length (Kishinouye, 1926). The adult fin ray-and-spine complement is attained at a length of only 15 mm, except for the pectoral in which rays continue to develop until about 30 mm length is reached. The trellis formed by the haemal arches is fully developed at about 27 mm, and the vertebrae are fully ossified at a length of 10.9 mm (Matsumoto, 1958). Certain characteristics of juvenile skipjack are listed in Table VII.

- Feeding

Little is known regarding the food of larval and juvenile skipjack. Hotta and Ogawa (1955) found that the stomachs of juveniles which had been consumed by adults contained fish and crustaceans, with a higher proportion of copepods than had been found in adult stomachs. Yuen (1959) found that among the smaller adults the diet consisted of a larger proportion of Crustacea and molluscs than that of the larger adults. Nakamura (MS) found that the stomachs of juvenile skipjack contained mysiids, euphausiids, amphipods, megalops larvae, copepods, squid and fish.

3.3. Adult history

3.3.1 Longevity

No direct evidence exists concerning the greatest age attained by skpjack. Brock (1954), on the basis of modal groups in the Hawaiian skipjack catch, hypothesized that the largest group (fork length about 75 to 85 cm) was composed of skipjack in their 4th year. If his estimate of the age at which the fish entered the fishery was in error by 1 year, which he stated was possible, the largest group would be in their 5th year. Aikawa and Kato (1938) used the growth rings on vertebrae to estimate the age of skipjack from Japanese waters. They estimated skipjack of the 72 to 80 cm length group to be 7th-year fish, or in age group VI. Recent tagging studies indicate that the growth deduced by Brock (1954) is more nearly correct than that estimated by Aikawa and Kato (1938). Skipjack larger than those found generally in the Hawaiian fishery are known to occur, and presumably these fish have also attained a greater age.

3.3.2 Hardiness

The literature contains no references to the hardiness of skipjack living in the normal range of their environment. Under abnormal conditions such as when fish are caught, either in nets or by hook-and-line, skipjack are thought to die quicker than some of the other tunas, such as albacore and yellowfin.

3.3.3 Competitors

In the commercial and experimental fisheries of the Pacific the following fish have been observed in or taken from feeding aggregations of skipjack, and should probably be considered competitors for food:

| | |
|---|---|
| Whale Shark (Rhineodon typus) | (Gudger, 1941) |
| Yellowfin Tuna (Neothunnus macropterus) | (Broadhead & Orange 1960) |
| Little Tunny (Euthynnus yaito) | (Data files, BLH) |
| Frigate Mackerel (Auxis sp.) | (Data files, BLH) |
| Albacore (Thunnus germo) | (Data files, BLH) |
| Dolphin (Coryphaena hippurus) | (Data files, BLH) |
| Rainbow Runner (Elagatis bipinnulatus) | (U.S. Fish and Wildlife Service, 196 |

These are the adult fishes known to compete with skipjack. In addition sea birds may be considered competitors, for both birds and skipjack feed on the same aggregations of forage organisms at the sea surface.

The literature contains no mention of small fish which may compete with juvenile skipjack.

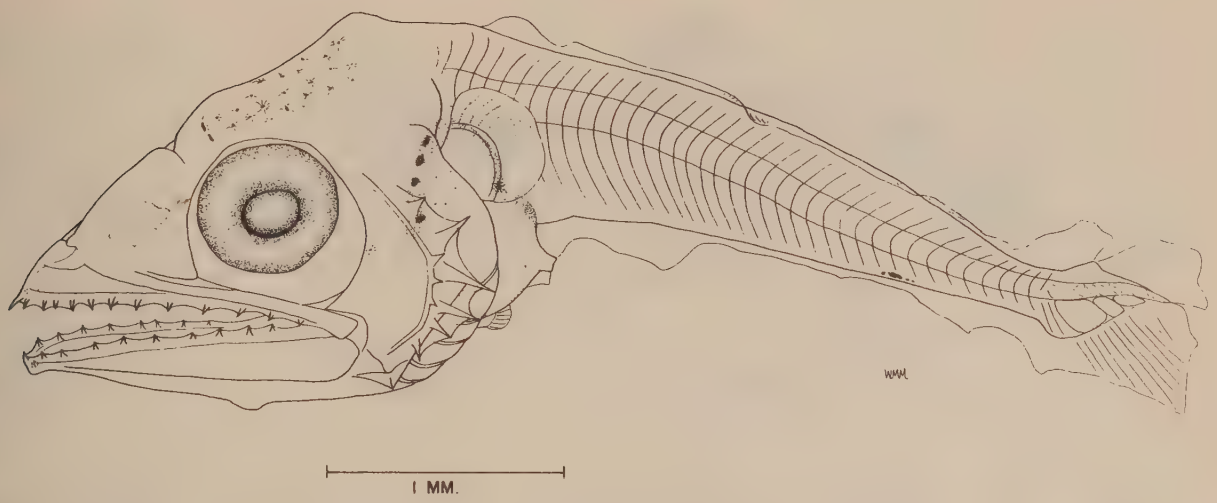


Fig. 6a Lateral view of larval skipjack, 5.35 mm length (from Matsumoto, 1958)

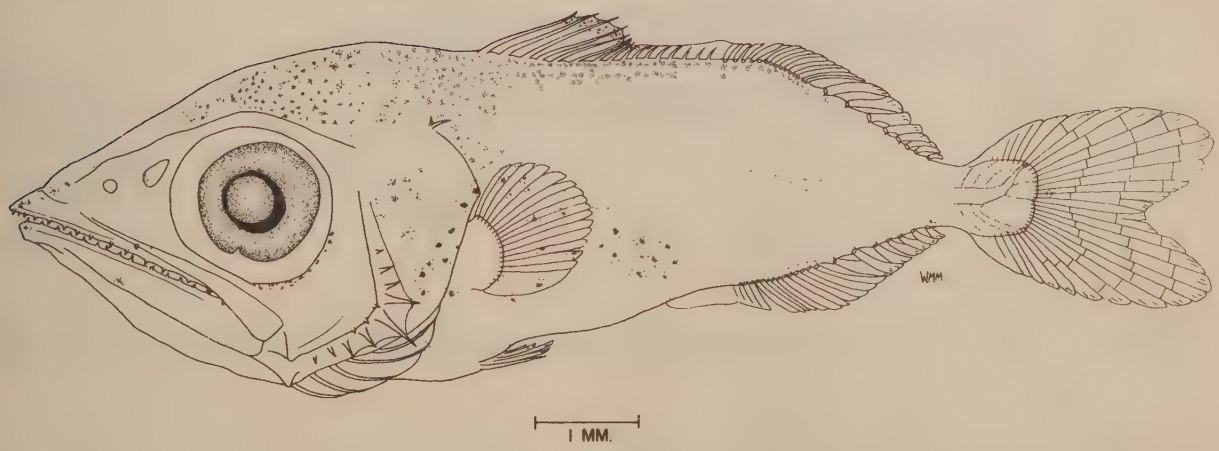


Fig. 6b Lateral view of larval skipjack, 10.9 mm length (from Matsumoto, 1958)

Fig. 6c Lateral view of juvenile skipjack, 21 mm length (from Schaefer and Marr, 1948)

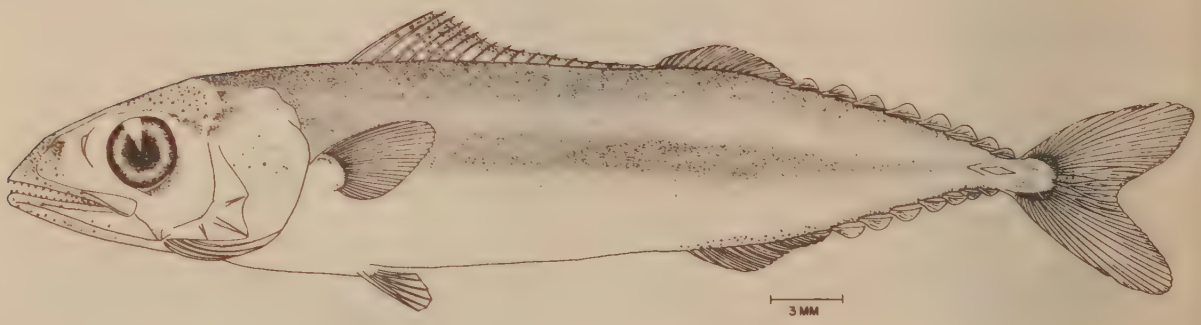


Fig. 6d Lateral view of juvenile skipjack, 47 mm length (from Matsumoto, in press)

Table VI

Summary of the more prominent diagnostic characters of skipjack larvae at various sizes (after Matsumoto, 1958, table 5)

| Characters | Length (mm) 3.7 | 5.35 | 7.1 | 8.75 | 10.9 | 14.5 |
|---|---|---|---|---|---|---|
| Teeth (1 side) | 4 upper; 6 lower | 13 upper; 11 lower | 15 each jaw | 16-18 each jaw | 15 each jaw | 15 upper; 17 lower |
| Preopercular spines | 3 | 6 | 7 | 7 | 9 | 8 |
| Myomeres | incomplete | 41 or 42 | 41 | 41-42 | - | - |
| Vertebrae | - | - | - | - | 20+21 (on a 9.85 mm. specimen) | 20+21 |
| 1st dorsal spines | - | - | 8; longest spine < 1/3 dorsal interspace [1] | 8 or 9 | 13; longest spine < 1/2 dorsal interspace [1] | 16; longest spine = 1/2 dorsal interspace [1] |
| 1st dorsal fin outline | - | - | - | - | concave | concave |
| Pigmentation [2] 1st dorsal fin | - | - | 1 chrom. [2] | 6 chrom. on outer fin edge | chrom. on outer edge to 12th spine | 6 or 7 chrom. on outer edge of fin |
| Middorsal line | no chrom. | no chrom. | no chrom. | 6-8 chrom. at base of 1st dorsal; 1 at origin of 2nd dorsal | chrom. to 1st finlet | Band of chrom. to 5th finlet |
| Midlateral line | no chrom. | no chrom. | no chrom. | no chrom. | 6 chrom. forward of caudal peduncle | Band of chrom. from 2nd to 5th finlet |
| Midventral line | 1 chrom. on caudal peduncle | 1 chrom. on caudal peduncle | 1 chrom. on caudal peduncle | 3 chrom. at base of anal; 1 on caudal peduncle | 4 chrom. at bases of anal and finlets; 1 on caudal peduncle | Band of chrom. at bases of anal and finlets; 1 on caudal peduncle |
| Tip of pectoral girdle | no chrom. | no chrom. | no chrom. | no chrom. | no chrom. | no chrom. |
| Anal opening | no chrom. | no chrom. | no chrom. | no chrom. | no chrom. | no chrom. |
| Midbrain | 10 chrom. over large area | 24 chrom. over large area | 50 chrom. over large area | 45+ chrom. over wide area | 80 chrom. over large area | numerous chrom. over large area |
| Forebrain | no chrom. | no chrom. | 2 chrom. | 2-3 chrom. | 4 chrom. | 12 chrom. |

Table VI

Summary of the more prominent diagnostic characters of skipjack larvae at various sizes (after Matsumoto, 1950, table 5) (con.)

| Characters | Length (mm) 3.7 | 5.35 | 7.1 | 8.75 | 10.9 | 14.5 |
|---|---|---|---|---|---|---|
| Mandible (other than at tip) | no chrom. | no chrom. | 1 chrom. 1/4 distance from tip | 1 chrom. 1/2 distance from tip | 1 chrom. | chrom. on 2/3 of length |

1/ distance between insertions of 1st and 2nd dorsal fins
2/ chrom. = chromatophores

Table VII
Some characters of larval and juvenile skipjack

| Author | Specimen length mm | Preopercle edge | Spines surface | Teeth: Each jaw | Teeth: Palatine | Fin rays and spines: 1st D. | 2nd D. | D. finlets | Anal finlets | Caudal | Pelvic | Pectoral | Gill rakers | Haemal trellis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kishinouye (1926) | 60-75 | - | - | - | ≥ 10 | - | - | - | - | - | - | - | - | - |
| Schaefer and Marr (1948) | 21 | 2 or 3 | - | - | Pres. | - | - | - | - | - | - | - | - | - |
| | 44 | 0 | - | - | - | XVI | 15 | 8 | 15 | 7 | - | - | 26 | 8 + 33 | - |
| Marr (1948) | 45 | - | - | - | Pres. | | | | | | | | | 6 + 32 | - |
| | 50 | - | - | - | Pres. | | | | | | | | | 6 + 32 | - |
| Wade (1950) | 13-27 | 9 | - | upper - 21<br>lower - 26 | 8 | XVI | 15 | 7 or 8 | 14 or 15 | 7 | - | - | - | - | - |
| Wade (1951) | 5 | 6 | 3 | 8 | - | - | - | - | - | - | - | - | - | - | - |
| | 7 | 6 | 3 | 10-12 | | 9 | 11 | 5 | 10 | 5 | - | - | - | - | - |
| | 9 | 8 | 3 | 16-18 | Pres. | 14 | 15 | 8 | 13 | 7 | - | - | - | - | - |
| Shimada (1951) | 35 | 1 | - | - | - | XVI | 14 | 8 | 15 | 7 | - | 6 | 27 | - | - |
| Matsumoto (1958) | 3.7 | 3 | 2 | upper - 4<br>lower - 6 | - | no fin rays | | | - | - | - | - | - | - | - |
| | 5.35 | 6 | 3 | upper - 13<br>lower - 11 | - | - | - | - | - | - | - | - | - | - | - |
| | 6.7 | 6 | 3 | - | - | IV | - | - | - | - | 18 | - | - | - | - |
| | 7.1 | 7 | 3 | - | - | VIII | Pres. | Pres. | - | | 12 + 11 | - | - | - | - |
| | 8.75 | 7 | 3 | 16-18 | 5 | VIII-IX | 10 | 6-7 | 10 | 6-7 | - | I + 5 | striations | - | - |
| | 10.9 | 9 | 3 | - | - | XIII | 15 | 8 | 14 | 7 | 16 + 16 | I + 5 | - | - | - |
| | 14.5 | - | - | upper - 15<br>lower - 17 | 6 | XVI | 15 | 8 | - | | 22 + 22 | - | 20 | - not developed | |
| | 20 | - | - | - | - | XVI | 15 | 8 | 15 | 7 | 22 + 22 | - | 20-21 | - 13th-22nd vert. partially closed | |
| | 27 | - | - | - | - | - | - | - | - | - | - | - | - | - 14th-33rd closed | |

Comments

- Disappear at about 40 mm
- Not present in specimens > 50 mm
- All spines and rays present at 15 mm.
- All spines and rays present at 9 mm
- All rays present at about 40 mm
- Trellis well-formed at 27 mm

### 3.3.4 Predators

The literature contains references to the following animals as predators on either juvenile or adult skipjack:

| | |
|---|---|
| Katsuwonus pelamis | Eckles 1949, Marr 1948 |
| Neothunnus macropterus | Kishinouye 1924, Reintjes and King 1953, Koga 1958 |
| Thunnus germo | Koga 1958 |
| Parathunnus sibi | Koga 1958 |
| Istiompax marlina | Royce 1957 |
| Makaira ampla | Royce 1957, Koga 1958 |
| Makaira audax | Royce 1957 |
| Makaira mazara | Shimada 1951 |
| Istiophorus orientalis | Shimada 1951 |
| Cybium chinense | Imamura 1949 |
| Alopias (sp.) | Strasburg 1958 |
| Acanthocybium solandri | Iversen and Yoshida 1957 |
| Gempylidae | Nakamura (MS) |

### 3.3.5 Parasites

The skipjack is listed by various authors as host for the following parasites:

Cestoda

| | |
|---|---|
| Tentacularia coryphaenae (Bosc 1802) | Yamaguti 1934 |
| Callotetrarhynchus speciosus (Linton 1897) | Yamaguti 1952 |
| Pelichnibothrium (larva) | Yamaguti 1934 |
| Rhyncobothrium | Kishinouye 1923 |

Trematoda

| | |
|---|---|
| Dinurus thynni Yamaguti 1934 | Yamaguti 1953 |
| Syncoelium katuwo Yamaguti 1938 | Yamaguti 1953 |
| Didymozoon filicolle Ishii 1935 | Yamaguti 1953 |
| Didymozoon longicolle Ishii 1935 | Yamaguti 1953 |
| Didymozoon minor Yamaguti 1934 | Yamaguti 1953 |
| Didymozoon auxis Taschenberg 1879 | Dawes 1947 |
| Didymocystis abdominalis Yamaguti 1938 | Yamaguti 1953 |
| Didymocystis bilobata Ishii 1935 | Yamaguti 1953 |
| Didymocystis dissimilis Yamaguti 1938 | Yamaguti 1953 |
| Didymocystis ovata Ishii 1935 | Yamaguti 1953 |
| Didymocystis simplex Ishii 1935 | Yamaguti 1953 |
| Didymocystis soleiformes Ishii 1935 | Yamaguti 1953 |
| Didymocystis submentalis Yamaguti 1938 | Yamaguti 1953 |
| Didymocystis wedli Ariola 1902 | Yamaguti 1953 |
| Didymocylindrus filiformis Ishii 1935 | Yamaguti 1953 |
| Didymoproblema fusiforme Ishii 1935 | Yamaguti 1953 |
| Neodiplotrema pelamydis Yamaguti 1938 | Yamaguti 1953 |
| Lobatozoum multisacculatum Ishii 1935 | Yamaguti 1953 |
| Kollikeria globosa Ishii 1935 | Yamaguti 1953 |
| Kollikeria orientalis (Yamaguti 1934) | Yamaguti 1953 |

| | |
|---|---|
| Kollikeria reniformis Ishii 1935 | Yamaguti 1953 |
| Tergestia laticollis | Manter 1940 |
| Hirudinella clavata | Manter 1940 |
| Hirudinella marina Garcin 1730 | Nigrelli and Stunkard 1947 |
| Hirudinella ventricosa (Pallas 1774) | Nigrelli and Stunkard 1947 |
| Tristomum laeve Verrill | Linton 1901 |

Nematodes

| | |
|---|---|
| Anisakis (larva) | Yamaguti 1941 |
| Philometroides sp. | Personal comm. J. Harada |

Acanthocephala

| | |
|---|---|
| Nipporhynchus ornatus (Van Cleave 1918) | Van Cleave 1940 |
| Acanthocephala (as a group) | Van Cleave 1940 |

Crustacea: Copepoda

| | |
|---|---|
| Caligus aliuncus Wilson | Wilson 1937 |
| Caligus bonito Wilson | Wilson 1905 |
| Caligus katuwo | Yamaguti 1936 |
| Caligus pelamydis Kroyer | Wilson 1905 |
| Caligus productus Dana 1854 | Wilson 1905 |
| Caligus tessifera Shiino | Shiino 1952 |
| Caligus thymni Dana 1852 | Wilson 1905 |
| Homoiotes bermudensis | Heegaard 1943 |
| Lepeophtheirus dissimulatus | Heegaard 1943 |
| Lepeophtheirus salmonis | Heegaard 1943 |

### 3.3.6 Greatest size

In the literature the greatest size mentioned is a length of about 1 m and a weight of 25 kg; Kishinouye (1923) states that this size is rarely attained.

### 3.3.7 Body temperature

Tuna as a group appear to have a body temperature higher than that of the surrounding waters, and in this respect differ from many other fish. Because of the problems of obtaining accurate measurements of body temperature of living skipjack, the only measurements have been of recently killed or dying fish. Uda (1941) reported the body temperature of skipjack to be 1° C to 3° C higher than the water from which they were taken, while Watanabe (1941) found the body temperature exceeded the water temperature by 2.1° C to 3.4° C. More recently Fukushima (1953) found that the temperature of the body cavity of skipjack was 1.4° C higher and the so-called "red muscle" was 5.9° C higher than the surrounding water temperature.

### 3.3.8 Biochemistry (chemical composition, amino-acids, seasonal variations)

This section is not intended to cover exhaustively the field of biochemistry of skipjack but only to give a brief review of the chemical composition of the fish and some of its organs.

Dill (1921) analyzed 10 skipjack from southern California waters and gave the following composition of the edible portion, i.e., the lateral musculature:

| | |
|---|---|
| Moisture[1/] | 65.94% |
| Solids | 34.06% |
| Ether Extracts | 7.37% |
| Ash | 1.30% |
| Total Nitrogen | 4.07% |

Suzuki, et al (1909) found that the soft tissues of skipjack contain 1.469% phosphorus on a dry weight basis. More recently Imanishi in a series of papers (Imanishi 1960a, 1960b, 1960d, 1960e, 1961a, 1961b, 1961c) has described in some detail the inorganic chemical constituents of the various organs and regions of the skipjack body. He lists (1960a) the following elements as occurring in the ash of skipjack, determination being by spectrographic analysis:

| | |
|---|---|
| Aluminum | Manganese |
| Calcium | Phosphorus |
| Carbon | Potassium |
| Chlorine | Silicon |
| Copper | Sodium |
| Iron | Sulphur |
| Lead | Tin |
| Magnesium | Zinc |

Horiguchi, Kashiwada, and Kakimoto (1953) found that the pyloric coeca contained the cations Al, Zn, Fe, Ca, Mg, Na, K, and traces of Ni, and Co, the anions S, P, Cl, and traces of Si. This differs from the list of elements shown by Imanishi (1960a) in containing nickel and cobalt and lacking copper, lead, manganese, and tin.

In additional studies of the pyloric coeca Kashiwada, Kakimoto and Horiguchi (1952) found a seasonal variation in the crude fat content of this organ, with the content highest in the spring, decreasing during the summer, increasing in early autumn, and decreasing slightly during late autumn.

Within the past two decades considerable work has been done in describing the protein structure of skipjack, a major portion of this work being done by Japanese scientists. Lukton and Olcott (1958) described the occurrence of free imidazole compounds in the muscle tissue of skipjack, including the amino acid histidine and the polypeptides carnosine and anserine.

Table VIII lists the amino-acids found in skipjack by Sugimura, et al (1954). Matsuura,

Table VIII
Amino-acids found in skipjack (Sugimura, et al., 1954) [1/]

| Amino-acid | Percent of total N in muscle | Amino-acid | Percent of total N in muscle |
|---|---|---|---|
| Arginine | 5.7 | Methionine | 1.0 |
| Aspartic acid | 6.3 | Phenyl-alanine | 2.0 |
| Glutamic acid | 5.9 | Proline | 4.3 |
| Glycine | 5.3 | Serine | 2.6 |
| Histidine | 5.7 | Threonine | 2.2 |
| Isoleucine | 3.1 | Tryptophane | 0.6 |
| Leucine | 4.2 | Tyrosine | 1.5 |
| Lysine | 9.1 | Valine | 7.2 |

1/ In addition to the above, Kakimoto, Kanazawa and Kashiwada (1953) reported the presence of Alanine, Cystine, and Ornithine.

1/ Dill does not list moisture, but Vinogradov (1953) attributes this figure to Dill (1921).

et al. (1954) listed most of these same amino-acids, and also noted slight differences in the composition of certain muscle layers.

In other studies Kashiwada (1952) found a seasonal change in the proteolytic enzyme activity in the pyloric coeca, with the highest activity during the spring, a decrease in the summer, and a fluctuating degree of activity during the fall. He noted that the enzyme activity appeared to follow the skipjack catch in the southern sea of Kyushu.

Other articles concerned with the biochemistry may be found in such journals as the Bulletin of the Japanese Society of Scientific Fisheries.

### 3.4 Nutrition and growth

#### 3.4.1 Feeding (time, place, manner, season)

- Time

Very little is known concerning the feeding habits of skipjack, and most existing knowledge has been deduced from variations in the catch rates of commercial fishing, or from variations in the volume of the stomach contents rather than from direct observation.

Uda (1940) stated that skipjack feed most actively in the early morning and somewhat less actively around noon and just before dusk. Nakamura (MS) hypothesized a midmorning period of active feeding, followed by a midday minimum and another period of active feeding just before sunset. Data from Yuen (1959) indicate minimum feeding activity in early afternoon with higher degrees of feeding activity in the morning and later afternoon, although the differences are not statistically significant.

- Place

Feeding skipjack are found in oceanic waters, both near to and far from land, over shallow or very deep water. Aside from these rather general statements which may be found in Kishinouye (1923), Suyehiro (1938), Nakamura (MS), and others, little is known regarding the place in which skipjack feed.

The vertical range over which skipjack feed is not known. However, it is known that they feed at and just below the surface, for it is at this time that it is possible to observe them. To a surface observer it appears that skipjack drive their prey to the surface, where both the fish and any nearby birds feed on the forage organisms. Fishermen utilize this behavior to locate fish schools, i.e., a flock of birds seen feeding at the surface may be taken to indicate a fish school in the same location.

- Manner

The exact manner in which skipjack feed is not well known. Kishinouye (1923) and Imamura (1949) state that skipjack may surround and concentrate schools of small fish and feed on the periphery, rather than make dashes into the center of this mass.

Recently, during the course of experimental fishing in Hawaiian waters, it has been possible to observe, through subsurface viewing ports, the actions of feeding skipjack. Certain of these observations, not yet published, will be reported here as personal communications from members of the Behavior Program at the Bureau of Commercial Fisheries Biological Laboratory at Honolulu. Skipjack swim in a horizontal attitude with their mouths slightly agape while searching for food. When taking prey of a size visible to an observer, the mouth is opened and then closed. Food organisms may be taken while the fish is moving in any direction from vertically upward to vertically downward.

- Season

Hotta and Ogawa (1955) found seasonal differences in the types of food consumed by skipjack in some areas and no differences in that consumed in other areas. In general the greatest differences were in the non-fish portion of the diet (excluding larval fish). It was felt that the diet was determined largely by the availability of particular items, e.g., when larval forms were abundant, large quantities of larvae would occur in the stomach contents.

Nakamura (MS) found little seasonal variation in the amount of fish consumed, but the amount of Crustacea consumed was lowest in

the winter and highest in summer, while the greatest amount of Mollusca was consumed in the winter and the least in the spring.

### 3.4.2 Food (type, volume)

The major food items have been described as fish, crustaceans, and molluscs by various authors (Kishinouye, 1923; Suyehiro, 1938; Welch, 1949; Ronquillo, 1953; Tester and Nakamura, 1957; Nakamura, MS; Waldron and King, 1962). In addition there are numerous other reports with brief mention of food as fish, crustaceans, and molluscs or squids. The most comprehensive studies to date are those by Hotta and Ogawa (1955), and unpublished manuscript by Nakamura (MS), and Waldron and King (1962). Table IX compiled from the above sources, lists the food organisms consumed by skipjack.

Hotta and Ogawa (1955) give the amount of food consumed in terms of grams of food per kilogram of body weight. The greatest weight of any one organism is 81.5 gm /kg body weight, with other values ranging down to a few tenths of a gram or to zero. Nakamura (MS) lists the average volume of stomach contents for skipjack under 60 cm length as between 4 and 24 cc, with considerable variation with time of day at which the fish were captured. Yuen (1959) lists values of up to 214 cc for large skipjack, i.e., above 60 cm, and gives values of 9.1 ml, 20.4 ml, and 35.6 ml as the mean volume of stomach contents for fish of less than 50 cm, 50 to 60 cm, and greater than 60 cm. fork length respectively.

With respect to size of organisms consumed, Waldron and King (1962) found that the average volume for individual Crustacea was 0.2 cc, for Mollusca 3.9 cc, and for fish 3.7 cc. The greatest average size of organisms consumed was 34.8 cc (a squid, Sepioteuthis sp.) and 34.3 cc (a fish, Decapterus pinnulatus).

Rather striking differences are observed in the food of skipjack from different areas. Waldron and King (1962) reported that fish, molluscs, and crustaceans make up respectively 75, 20, and 4 percent of the diet of central Pacific skipjack, while Schaefer (1960) reports these same groups contribute about 33, 4, and 62 percent of the diet of eastern Pacific skipjack.

### 3.4.3 Growth

Hayashi (1958) reviewed the age determinations of Pacific tunas, including skipjack. He noted considerable disagreement between the only works describing growth and age of skipjack, those by Aikawa (1937) and Aikawa and Kato (1938) working with skipjack from Japanese waters, and that by Brock (1954) working with skipjack from Hawaiian waters. Hayashi attributed part of the difficulty in aging skipjack by means of rings on hard parts, the method followed by Aikawa, to the slight seasonal change of the environment in which skipjack live.

In their study of the age of skipjack, using vertebral rings, Aikawa and Kato (1938) gave the following lengths, weights, and growth rates for skipjack from Japanese waters.

| Age group | Length range cm | Weight range kg | Growth rate |
|---|---|---|---|
| 0 | < 27 | < 0.4 | - |
| I | 27 - 37 | 0.4 - 1.3 | 0.90 |
| II | 37 - 46 | 1.3 - 2.5 | 0.69 |
| III | 46 - 55 | 2.5 - 4.1 | 0.53 |
| IV | 55 - 64 | 4.1 - 6.5 | 0.46 |
| V | 64 - 72 | 6.5 - 9.5 | 0.37 |
| VI | 72 - 80 | 9.5 -13.0 | 0.31 |
| VII | > 80 | > 13.0 | ? |

This growth is considerably different from the growth as determined by Brock (1954) based on the presence of modes in the size distribution of Hawaiian skipjack. Brock's growth curve shows that at the end of periods of 1, 2, 3, and 4 years skipjack may attain lengths of 41 cm, 69 cm, 79 cm, and 82 cm. respectively. His estimates are thus greater than those of Aikawa and Kato by a factor approaching two. Kawasaki (1955b, his figure 8) shows that Japanese skipjack of the "Archipelago group" grow about 18 cm during the third year and 12 cm during the fourth year. This is much more rapid growth than that estimated by Aikawa and Kato and more nearly approaches the growth hypothesized by Brock (1954) for Hawaiian skipjack.

On the basis of growth of tagged skipjack, released at a size of about 2.5 kg, Yamashita and Waldron (1959) estimated an increase in weight of about 0.36 kg per month, or about

Table IX
A list of food organisms consumed by Katsuwonus pelamis

| | Hotta and Ogawa (1955) Japanese waters | Waldron and King (1962) | Welch (1949) Hawaiian waters | Ronquillo (1953) Philippine waters | Nakamura (MS) South Pacific - Marquesas |
|---|---|---|---|---|---|
| Arthropoda | X | X | X | X | X |
| Crustacea | X | X | X | X | X |
| Copepoda | | X | | | |
| Malacostraca | X | X | | X | X |
| Mysidacea | | X | | | |
| Mysiidae | | X | | | |
| Isopoda | | X | | | |
| Amphipoda | | X | | X | X |
| Hyperiidae | | X | | | |
| Phronimidae | | X | | | |
| Phronima sp. | | X | | | |
| Phrosinidae | | X | | | |
| Pronoidae | | X | | | |
| Oxycephalidae | | X | | | |
| Oxycephalus sp. | | X | | | |
| Euphausiacea | X | X | | | X |
| Euphausiidae | | X | | | |
| Thysanopoda tricuspidata | | X | | | |
| Euphausia sp. | | X | | | |
| Decapoda | X | X | X | X | X |
| Natantia | X | X | | X | X |
| Pandalidae | | X | | | |
| Heterocarpus ensifer | | X | | | |
| Reptantia | | X | | X | |
| Scyllaridae | | X | | | |
| Palinuridae | | | | X | |
| Phyllosoma larvae | | | | | X |
| Nephropsidae | | X | | | |
| Enoplometra occidentalis | | | | | |
| Brachyuran zoea larvae | | | | X | |
| Brachyuran megalops larvae | | X | | X | X |
| Crab larvae | | | X | | |
| Stomatopoda | | X | X | X | X |
| Squillidae | | X | X | | |
| Squilla sp. | | X | | | |
| Pseudosquilla sp. | | X | | | |
| Pseudosquilla ciliata | | X | | | |
| Pseudosquilla occulata | | X | | | |
| Lysiosquilla sp. | | X | | | |
| Lysiosquilla maculata | | | X | | |
| Odontodactylus sp. | | X | X | | |

Table IX
A list of food organisms consumed by Katsuwonus pelamis (con.)

| | Hotta and Ogawa (1955) Japanese waters | Waldron and King (1962) | Welch (1949) Hawaiian waters | Ronquillo (1953) Philippine waters | Nakamura (MS) South Pacific - Marquesas |
|---|---|---|---|---|---|
| Odontodactylus hanseni | | X | | | |
| Gonodactylus sp. | | X | | | |
| Coronida sp. | | X | | | |
| Mollusca | X | X | X | X | X |
| Gastropoda | | X | | | X |
| Heteropoda | | X | | | X |
| Atlantidae | | X | | | |
| Atlanta sp. | | X | | | |
| Pteropoda | | X | | | X |
| Carolinidae | | X | | | |
| Carolinia sp. | | X | | | |
| Cephalopoda | X | X | X | X | X |
| Octopoda | X | X | X | X | X |
| Argonautidae | X | X | | X | X |
| Argonauta sp. | X | | | | |
| Decapoda | X | X | X | X | X |
| Loliginidae | X | X | | | |
| Sepioteuthis sp. | | X | | | |
| Loligo bleederi | X | | | | |
| Ommastrephidae | | X | | | |
| Ommastrephes hawaiiensis | | X | | | |
| Symplectoteuthis sp. | | X | | | |
| Sepiolidae | X | | | | |
| Euprymna marsei | X | | | | |
| Chordata | X | X | X | X | X |
| Tunicata | | X | | | X |
| Salpidae | | X | | | |
| Vertebrata | X | X | X | X | X |
| Pisces | X | X | X | X | X |
| Albulidae | | X | | | |
| Dussumieriidae | X | | X | | |
| Spratelloides japonicus | X | | | | |
| Spratelloides delicatulus | | | X | | |
| Clupeidae | X | X | | X | |
| Sardinella sp. | | | | X | |
| Etrumeus micropus | | X | | | |
| Gonostomidae | X | | | | |
| Sternoptychidae | X | X | | X | |
| Sternoptyx diaphana | X | X | | X | |
| Stomiatidae | | X | | X | |
| Idiacanthidae | | | | | X |

Table IX
A list of food organisms consumed by Katsuwonus pelamis (con.)

| | Hotta and Ogawa (1955) Japanese waters | Waldron and King (1962) | Welch (1949) Hawaiian waters | Ronquillo (1953) Philippine waters | Nakamura (MS) South Pacific - Marquesas |
|---|---|---|---|---|---|
| Synodontidae | | X | X | X | X |
| Paralepidae (= Sudidae) | X | X | | X | |
| Lestidium prolixom | X | | | | |
| Lestidium philippina | | | | X | |
| Alepisauridae | X | X | | | |
| Alepisaurus borealis | | X | | | |
| Myctophidae | X | X | | X | X |
| Diaphus sp. | | X | | | |
| Diaphus caeruleus | X | | | | |
| Belonidae | | | | | X |
| Scomberesocidae | X | X | | | |
| Cololabis sp. | | X | | | |
| Cololabis saira | X | | | | |
| Hemirhamphidae | | X | | X | |
| Exocoetidae | X | X | X | X | X |
| Parexocoetus brachypterus | | X | | | |
| Exocoetus obtusirostris | X | | | | |
| Exocoetus volitans | X | | | | |
| Cypselurus poecilopterus | X | | | | |
| Oxyporhamphidae | X | | | | |
| Aulostomidae | | | X | | |
| Aulostomus chinensis | | | X | | |
| Fistulariidae | | X | | X | X |
| Macrorhamphosidae | X | | | | |
| Macrorhamphosus japonicus | X | | | | |
| Syngnathidae | | X | X | X | |
| Hippocampus sp. | | X | | | |
| Hippocampus kuda | | | X | | |
| Holocentridae | X | X | X | X | X |
| Holocentrus sp. | | X | | | |
| Holocentrus spinosissimus | X | | | | |
| Holocentrus diadema | X | | | | |
| Myripristis murdjan | X | | | | |
| Grammicolepidae | X | | | | |
| Xenolepidichthys dalgleishi | X | | | | |
| Antigonidae | | | | X | |
| Sphyraenidae | X | X | | | X |
| Atherinidae | | X | | | |
| Polynemidae | X | | | | |
| Polydactylus plebius | X | | | | |
| Serranidae | X | | | | X |

Table IX
A list of food organisms consumed by Katsuwonus pelamis (con.)

| | Hotta and Ogawa (1955) Japanese waters | Waldron and King (1962) | Welch (1949) Hawaiian waters | Ronquillo (1953) Philippine waters | Nakamura (MS) South Pacific - Marquesas |
|---|---|---|---|---|---|
| Epinephelidae | X | | | | |
| Kuhliidae | | X | | | |
| Priacanthidae | X | X | X | X | X |
| *Priacanthus cruentatus* | | X | X | | |
| *Priacanthus boops* | X | | | | |
| *Priacanthus macracanthus* | X | | | | |
| Labracoglossidae | X | | | | |
| *Labracoglossa argentiventris* | X | | | | |
| Carangidae | X | X | X | X | X |
| *Caranx uraspis* | X | | | | |
| *Decapterus* sp. | | | | X | |
| *Decapterus muroadsii* | X | | | | |
| *Decapterus russellii* | X | | | | |
| *Decapterus pinnulatus* | | X | X | | |
| *Trachurus japonicus* | X | | | | |
| *Trachurops crumenophthalus* | | X | X | | |
| *Megalaspis cordyla* | | | | X | |
| *Scomberoides sanctipetri* | | X | | | |
| Menidae | X | | | | |
| *Mene maculata* | X | | | | |
| Bramidae | | X | X | X | X |
| *Collybus drachme* | | X | | | |
| Coryphaenidae | X | X | | X | X |
| *Coryphaena hippurus* | X | X | | X | |
| Emmelichthyidae | X | | | | X |
| *Erythrocles schlegeli* | X | | | | |
| Lutianidae | X | | | | X |
| *Etelis* sp. | X | | | | |
| Denticidae | X | | | | |
| *Gymnocranius griseus* | X | | | | |
| Caesionidae | X | | | | |
| *Caesio chrysozonus* | X | | | | |
| *Caesio tile* | X | | | | |
| *Caesio* sp. | | | | X | |
| Mullidae | X | X | X | X | X |
| *Mulloidichthys auriflamma* | | X | | | |
| Pempheridae | X | | | | |
| *Parapriacanthus bryceformes* | X | | | | |
| Kyphosidae | | | | | X |
| Chaetodontidae | X | X | X | X | X |
| Pomacentridae | | | | X | X |

Table IX
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| | Hotta and Ogawa (1955) Japanese waters | Waldron and King (1962) | Welch (1949) Hawaiian waters | Ronquillo (1953) Philippine waters | Nakamura (MS) South Pacific - Marquesas |
|---|---|---|---|---|---|
| Pomacanthidae | | X | | | |
| Chiasmodontidae | | | | X | |
| Blennidae | | X | | | X |
| Brotulidae | | X | | | |
| Ammodytidae | X | X | | | X |
| Bleekeria sp. | | X | | | |
| Embolichthys mitsukuri | X | | | | |
| Siganidae | X | | | X | |
| Teuthidae | | | | X | |
| Acronurus larvae | | | | X | |
| Zanclidae | X | | | | |
| Zanclus cornutus | X | | | | |
| Acanthuridae | X | X | X | | X |
| Acanthurus sp. | | | X | | |
| Gempylidae (= Acinaceidae) | X | X | X | X | X |
| Gempylus serpens | | X | | X | |
| Rexia solandri | | | | X | |
| Neolatus tripes | X | | | | |
| Mimasea taeniosoma | X | | | | |
| Acinacea notha | X | | | | |
| Dicrotus sp. | X | | | | |
| Trichiuridae | X | | | X | |
| Lepidopus tenuis | X | | | | |
| Scombridae (including Thunnidae) | X | X | X | X | X |
| Neothunnus macropterus | | X | | | X |
| Euthynnus sp. | | | | | X |
| Euthynnus yaito | | X | | X | |
| Auxis sp. | | | | X | X |
| Auxis thazard | X | | | | |
| Auxis tapeinosoma | X | | | | |
| Katsuwonus pelamis | X | X | | | X |
| Scomber sp. | | X | | | |
| Scomberomoridae | X | X | | | |
| Scomberomorus sp. | X | | | | |
| Histiophoridae | X | | | | |
| Tetragonuridae | | X | | | |
| Nomeidae | X | X | | | X |
| Cubiceps sp. | | X | | | |
| Nomeus albula | X | | | | |
| Centrolophidae | | | X | | |
| Scorpaenidae | | X | | | X |

Table IX
A list of food organisms consumed by Katsuwonus pelamis (con.)

| | Hotta and Ogawa (1955) Japanese waters | Waldron and King (1962) | Welch (1949) Hawaiian waters | Ronquillo (1953) Philippine waters | Nakamura (MS) South Pacific - Marquesas |
|---|---|---|---|---|---|
| Pontinus sp. | | X | | | |
| Scorpaena sp. | | X | | | |
| Setarchus sp. | | X | | | |
| Triglidae | | | X | | |
| Peristedidae | X | | | | |
| Satyrichthys amiscus | X | | | | |
| Platycephalidae | | | | | X |
| Dactylopteridae | | | | X | X |
| Echeneidae | X | | | | |
| Remora remora | X | | | | |
| Triacanthidae | | | | X | |
| Balistidae | X | X | X | X | X |
| Balistes ringens | | X | | | |
| Monacanthidae | X | X | X | | X |
| Ostraciidae | X | X | X | X | X |
| Lactoria diaphanus | X | X | | | |
| Lactoria fornasina | | | X | | |
| Tetraodontidae | X | X | | X | |
| Sphaeroides exilis | X | | | | |
| Canthigasteridae | X | X | | | |
| Canthigaster rivulatus | X | | | | |
| Diodontidae | X | X | | X | X |
| Diodon holacanthus | | X | | | |
| Molidae | X | X | | | |
| Ranzania truncata | | X | | | |
| Masturus lanceolatus | X | | | | |
| Pegasidae | | | | | X |

Additional food organisms not listed by the above authors:

Chaetodon corallicola: Chaetodontidae - Strasburg (1961)
Holocentrus lacteoguttatus: Holocentridae - do.
Parupeneus sp.: Mullidae - do.
Synodus variegatus: Synodontidae - do.
Symplectoteuthis oualaniensis: Decapod Mollusca - do.
Vinciguerria lucetia - Schaefer (1960)
Pleuroncodes planipes: Decapoda: Crustacea - Schaefer (1959)

4.36 kg per year. This growth is more similar to that estimated by Brock than to the estimates of Aikawa and Kato (1938). In the eastern Pacific, Schaefer, Chatwin, and Broadhead (1961) reported a growth of 12.1 cm and 2.7 kg per year for skipjack tagged at a length of between 40.0 and 55.0 cm. These same authors also stated that the growth of tagged skipjack was substantially slower than that of untagged skipjack. However, Schaefer (1961a), using length frequency data, indicates a growth of only 12 to 15 cm per year for skipjack of about 45 cm length.

### 3.4.4 Relation of growth to feeding, to other activities, and to environmental factors

Kawasaki (1955a, 1955b) studying changes in the size composition of skipjack catches from certain areas near Japan, found that growth of the "sedentary" and "migratory" groups differed. He concluded that the sedentary groups had a low rate of growth during the summer because they were maturing sexually. In contrast, the migratory groups had a high rate of growth during the summer because they were on a feeding migration. During the winter the growth of these two groups reversed as did their habits. The summer sedentary-sexually maturing group became a feeding-migratory group, while the summer migratory-feeding group became a sedentary-sexually maturing group.

## 3.5 Behavior

### 3.5.1 Migrations and local movements

Descriptions of the migrations of skipjack exist only for areas with commercial fisheries, but not for all such areas. In the western Pacific the migrations into and through the Japanese fishery have been described by Uda and Tsukushi (1934), Sasaki (1939), Imamura (1949), Tauchi (1943), Shapiro (1948), Kawasaki (1955a, 1955b), and others. Imamura (1949) classified the skipjack of the western Pacific according to their migratory behavior as follows: (1) Skipjack which spend their whole lives in the tropical seas south of latitude 23° N, (2) skipjack which make a great circular migration in the North Equatorial Current in the spring and summer, and (3) skipjack which move north and south in the Kuroshio current system. The migratory skipjack are thought to follow three routes (Fig. 7): (1) Along the North Equatorial Current past the Philippines, Taiwan, and Okinawa to the Satsunan area and thence gradually northward. (2) Another group is thought to move from the South Seas Area to the Zunan area along the northerly warm current of the Kuroshio which originates in the waters near the Bonins in the spring. (3) The third route is northward between the North Equatorial Current and the northerly warm current of the Ogasawara region to the vicinity of the Kinan reefs in the Kinan area (30°10' N, 136°45' E ). These routes have been deduced from studies of changes in the concentrations of schools during the fishing season, studies of the current systems, and studies of the size and condition of the fish.

Tauchi (1943) divided the skipjack contributing to the Japanese fishery into (1) migratory and (2) resident types. He described the migratory types as originating in the "South Seas Area" where they spend their larval and juvenile existence. The majority of the migratory fish which move into the Japanese fishery are in age-group III, with smaller numbers of age-groups II and IV (age determined from Aikawa's tables). After they have migrated into Japanese waters Tauchi (1943) concludes that these skipjack return to the South Seas Area and do not undertake a second migration. Kawasaki (1955a, 1955b) describes in considerable detail the movements of skipjack within certain areas to the southwest and southeast of Japan. He portrays a migration up and down the Ryukyu Is. archipelago, and a similar migration along the Bonin Is. and the Northeastern Sea Area.

In the central Pacific there is evidence, from changes in the composition and amount of the catch, that skipjack, possibly both large and small, but especially those above 15 pounds in weight (about 7 kg ), migrate into the Hawaiian fishery during the spring (April to June). The location of these fish prior to their entry into the Hawaiian fishery is not known. In late summer or fall (August to October) this group of large fish disappears from the Hawaiian fishery, but their destination is not known.

Within the Hawaiian fishery skipjack appear to follow a rather random pattern of movement in both easterly and westerly directions along

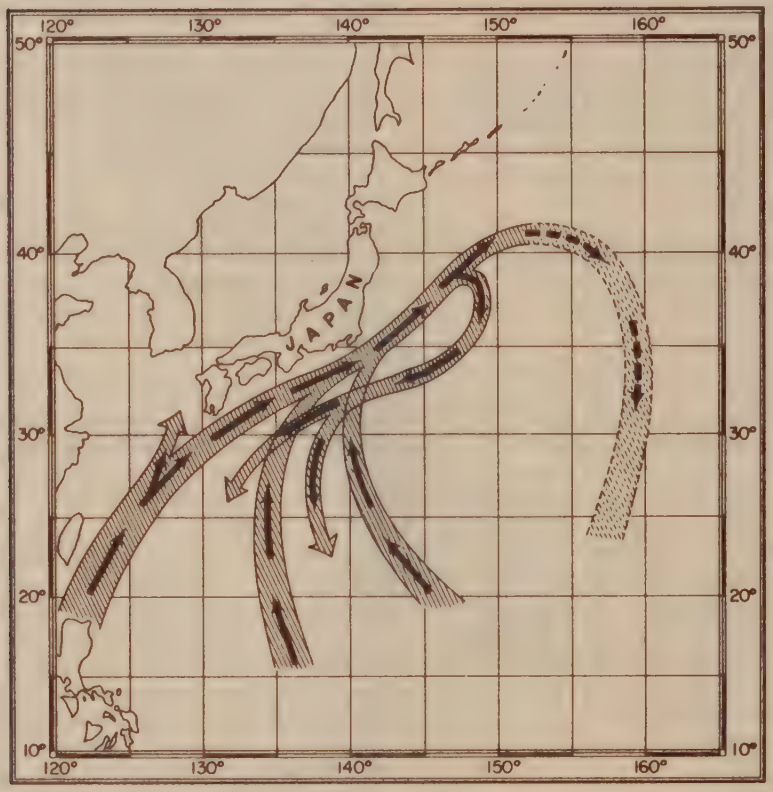


Fig. 7 Migrations of skipjack in the western Pacific Ocean (according to Imamura, 1949; Kawasaki, 1955a, 1955b)

the archipelago, as shown by the recovery of tagged fish.

On the basis of movements of tagged skipjack, Blunt and Messersmith (1960) and Schaefer, Chatwin, and Broadhead (1961) described the movements of skipjack in the eastern Pacific.

None of the skipjack tagged and released in the eastern Pacific fishery have been recovered in other fisheries of the Pacific, e.g., the Hawaiian or Japanese. On this basis it is concluded that there is little if any interchange of fish on an oceanwide scale such as has been observed for albacore.

Taken by quarters of the year, the within-fishery migration of skipjack according to Blunt and Messersmith (1960) and Schaefer, Chatwin, and Broadhead (1961) appears to be as described below, and shown in Fig. 8. In this description the term "northern area" refers to all of the eastern Pacific fishery north of latitude 10° N, while the term "southern area" includes all south of this latitude. The term "region" will be used to indicate subdivisions of these areas.

(1) January, February, March: Skipjack tagged in the northern area tended to be recovered in the region in which they were released. Some skipjack moved south from the Gulf of California region into the region off southern Mexico.

In the southern area there was considerable interchange of skipjack between regions. Some fish moved in towards a location known as the "14-fathom spot" (about latitude 9° S, longitude 79°-80° W ) from the Galapagos Is. There was also some interchange between the "14-fathom spot" and the Gulf of Guayaquil, in both a north and south direction.

(2) April, May, June: Skipjack in the northern area appear to be restricted to within-region migrations, except for a movement from the Revillagigedo Is. north to the Pacific coast of Baja California. Within the region off Baja California, there is a pronounced northerly migration.

Within the southern area there is evidence of both northerly and southerly migrations at this time of year. The predominant movement appears to be north from the "14-fathom spot" to about latitude 0° off the Colombian coast, and south from the Gulf of Panama to the same region. However, there is still some southerly migration from near the Gulf of Guayaquil to the "14-fathom spot."

(3) July, August, September: As during the previous quarters there is no evidence of inter-regional migration in the northern area. Within the Baja California region the movement has become predominantly southerly, although there is still some northerly movement.

In the southern area there was a predominantly southern movement from the Gulf of Panama to the Colombian and Ecuadorian coasts as well as rather short-distance northerly and southerly movement along the coasts of Peru and Ecuador. A few skipjack moved from the "14-fathom spot" to off the Gulf of Guayaquil.

(4) October, November, December: In the northern area there was evidence of only within-region movement.

In the southern area the predominant movement was from the Gulf of Panama south to the coasts of Colombia, Ecuador, and northern Peru. From the "14-fathom spot" there was considerable movement north to the Gulf of Guayaquil and some movement offshore to north of the Galapagos Is. Skipjack also moved south from the "14-fathom spot" to off the northern portion of Chile (about latitude 19°-20° S ).

### 3.5.2 Schooling

Skipjack are known to be a schooling fish during their adult life, and probably during their juvenile life (Kishinouye, 1923; Brock, 1954). Brock (1954) in studying samples from commercial landings noted that skipjack school by size, i.e., there was less variation in length within samples from single schools than within the total landings from which the samples were drawn. He attributed this size segregation to a dependence of maximum swimming speed upon length of the fish. Among 120 samples of about 34 fish each from pure schools he found a mean range in length of 11.3 cm, while for the landings of the period the range was 47 cm. Broadhead and Orange

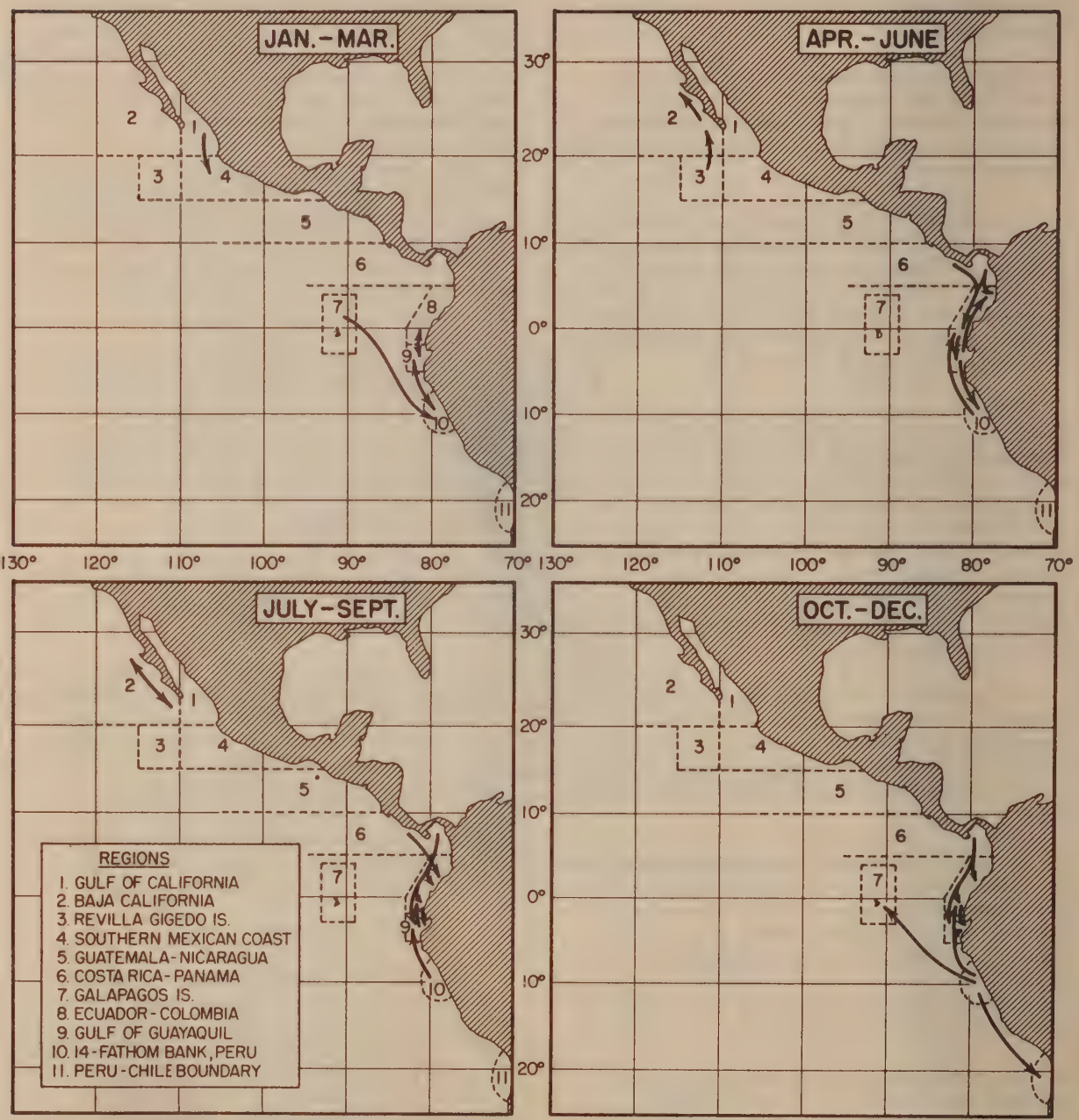


Fig. 8 Migrations of skipjack in the eastern Pacific Ocean (according to Blunt and Messersmith, 1960; Schaefer, Chatwin and Broadhead, 1961)

(1960) noted that in the eastern Pacific "individuals composing single schools are more nearly like each other than would be expected if they were drawn at random from the whole population." Among 64 samples of about 25 fish each from single schools the average range was about 9.6 cm, while the range for all samples was 30.6 cm.

Skipjack frequently form feeding aggregations with other tuna, especially yellowfin (Neothunnus macropterus), and these aggregations are usually referred to as "mixed schools." Skipjack in these mixed schools, which might more correctly be called mixed feeding aggregations, may associate with yellowfin considerably larger than themselves (Broadhead and Orange, 1960). Underwater observations show that in mixed feeding aggregations of skipjack and yellowfin, each species moves and responds to chum independently of the other species (U.S.F.W.S., 1961).

Skipjack schools may occasionally be very large, but at least to an observer on the surface the majority are of moderate size. Orange, Schaefer, and Larmie (1957) state that the average catch of skipjack per school by purse seiners is 13.8 tons, while the greatest catch which they list is between 130.0 and 134.9 tons; very few catches are above 75 tons. When it is considered that skipjack catches in the eastern Pacific fishery are composed predominantly of fish between 4 and 10 pounds, (Shimada and Schaefer, 1956) then 100 tons would represent between 20 and 50 thousand fish. Since it is unlikely that all fish in a school are captured, these figures then represent the minimum number of skipjack in a large school.

In the Japanese fishery the behavior of schools, as shown by the catch from different schools, has been shown to be related in different ways to objects with which the schools are associated, to oceanographic and sea conditions, and to certain aspects of feeding (Uda, 1933; Suyehiro, 1938; Sasaki, 1939; Kimura, 1954; Hotta, Kariya, and Ogawa, 1959; and Inoue, 1959).

Strasburg (1961) studied the diving behavior of skipjack schools during fishing operations in Hawaiian waters as related to items of diet. He found that skipjack feeding on juvenile Holocentrus lacteoguttatus and post-larval Synodus variegatus were more prone to leave the surface during fishing operations than were skipjack feeding on other animals. Yuen (1959) found that distance from land, stomach content and stage of digestion, and swimming characteristics of food fish consumed affected the response of skipjack to chum.

### 3.5.3 Reproductive behavior

Little is known concerning the reproductive behavior of skipjack. Brock (1954) noted that skipjack with fully ripe ova are seldom taken in the Hawaiian fishery, and Kishinouye (1923) stated that skipjack with ripe reproductive elements seemed to fast.

It appears that in ova diameter distributions the mean diameter of advanced ova is about 0.7 mm and of ripe ova about 1.0 mm, and no group of ova have been observed with a mean between these values. As Brock (1954) points out, this implies that during the period in which the ova are increasing from about 0.7 to 1.0 mm female skipjack are unavailable to a commercial fishery, especially a pole-and-line fishery. Further, if this increase required a significant period of time, say one month, and spawning of large numbers of fish occurred at the same time, then it should be possible to detect the spawning period through changes in the sex ratio of the catch. This does not appear to be the situation, so it might be inferred from Brock's statements that (1) skipjack spawn in small groups, say as individual schools, over a protracted period, (2) the time required for ova to increase from 0.7 to 1.0 mm is relatively short, or (3) male skipjack become unavailable in the same proportion and at the same time as the females.

## 4 POPULATION (STOCK)

For the population as a whole there is no information on structure, size and density, natality and recruitment, mortality and morbidity, dynamics, and other relations involving the population. Concerning a portion of the population, that part susceptible to capture by commercial fishing methods, there is a rather sparse literature on a few aspects of the population. Therefore, comments in the following sections are applicable only to the commercially caught segment of the population, in general those fish above 30 cm in fork length.

### 4.1 Structure

#### 4.1.1 Sex ratio

The sex ratio for that portion of the population caught in commercial and exploratory fishing may depart significantly from 1:1 at certain times of the year (Brock, 1954). Table X summarizes the sex ratios observed in different areas. Perhaps the most striking departures from the 1:1 ratio are those observed by Schaefer and Orange (1956) in the eastern Pacific and by Marr (1948) in the Marshall Is. area.

#### 4.1.2 Age and size composition

Since no commercial fishery captures skipjack over the entire age range, it is clear that samples drawn from a commercial fishery are not representative of the population.

The different methods of determining the age of skipjack of different sizes has been reviewed by Hayashi (1958), who pointed out the considerable difference in age as estimated by Aikawa (1937) and Aikawa and Kato (1938) compared to the age estimated by Brock (1954). Because of these differences it is difficult to make valid comparisons of age composition of the catch as reported by various authors. In this section reference to age will be followed, when such information is available, by a weight or length designation.

The bulk of the commercial catch from Japanese waters is, according to various authors (Aikawa, 1937; Imamura, 1949; Tauchi, 1943; Kawasaki, 1955a and 1955b), composed of skipjack in their 3rd and 4th years. Smaller quantities of fish in their 2nd and 5th years appear regularly in the landings, and occasionally fish of an older age (6th and 7th-year fish) are caught. All of the Japanese workers refer to the age as determined by Aikawa and Kato

Table X
Sex ratios among populations of commercially caught skipjack

| Area and period | Author | % Male | % Female | Number in sample |
|---|---|---|---|---|
| Western Pacific | Kuronuma, Kafuku, | | | |
| Japanese Fishery | and Kikawa (1949) | | | |
| | and Yabe (1954) | 52.1 | 47.9 | 853 |
| Northern Marshall Is. | Marr (1948) | 61.5 | 38.5 | 179 |
| Central N. Pacific | Brock (1954) | | | |
| Hawaiian Fishery | | | | |
| March to August | | 50.8 | 49.2 | 2,452 |
| September to December | | 59.2 | 40.8 | 1,299 |
| Eastern Pacific | Schaefer and Orange | | | |
| January - December | (1956) | 39.1 | 60.9 | 1,815 |
| Central S. Pacific | Wilson and Rinkel (1957) | | | |
| | Wilson, Nakamura, and | | | |
| | Yoshida (1958) | | | |
| | Yoshida (1960) | 51.2 | 48.7 | 2,272 |
| Philippines | Wade (1950) | 46.2 | 53.8 | 331 |

(1938), and their age groups with corresponding sizes are shown in Section 3.4.3, p. 3:15 of this synopsis. Briefly, fish in their 2nd, 3rd, 4th, 5th, and 6th years are believed to be about 32 cm, 43 cm, 50 cm, 60 cm, and 68 cm respectively. Fig. 9 shows the size composition of a sample of the landings in Japan with age according to Aikawa and Kato (1938).

In the Hawaiian fishery Brock (1954) has hypothesized the presence of three age groups. These groups are usually centered around lengths of 45 cm, 79 cm, and 80 cm. The greatest amount of the landings, by weight, is from the 70-cm group, followed in importance by the 45-cm and then the 80-cm groups. There is considerable monthly and annual variation in the importance of these different groups, although the 80 cm group is seldom of great importance. Brock (1954) tentatively assigned an age of 1 year to the 45-cm fish, 2 years to the 70 cm group, and 3 years to the 80 cm group, and on this basis the most important group in the Hawaiian area would be the 2-year-old skipjack. Fig. 10 shows a composite size composition for the commercial landings.

For the eastern Pacific fisheries, only size data are available. The bulk of the catch consists of skipjack less than 65 cm long, with a small percentage of the catch being fish larger than this size. Hennemuth (1957) states, "In general, however, the catch is composed primarily of one or two age groups of fish, the numbers of larger sized (and older) fish caught being very limited." Hennemuth (1959), in a study of morphometrics of skipjack, lists a range of size from 39.6 to 75.1 cm, however, Hennemuth (1957) and Broadhead and Orange (1960) show that the bulk of the catch is composed of skipjack between 45 and 65 cm in length. It should be noted that the lower limit of the range is biased to an unknown extent by the existence of a minimum legal size limit which is usually set at 4 pounds or about 45 cm length (Schaefer, 1961a). Fig. 11 shows the size composition in a relatively small sample of skipjack from the eastern Pacific.

On the basis of the work in the central and western Pacific, it appears that skipjack up to a size of about 90 cm are present in the population, and that either four or eight age groups are included depending upon the method used to determine age. The true age and size composition of the population is not known.

## 4.2 Size and density of population

### 4.2.2 Changes in size

The size of the commercially fished population apparently fluctuates from year to year in each of the different fisheries. This is indicated by variations in the landings from year to year, although factors other than population size contribute to variations in the amount of skipjack landed. Examples of these variations in population size are to be found in the western, eastern, and central Pacific fisheries. The range in catch over a number of recent years is shown below.

| Fishery | Years | Minimum (in metric tons) | Maximum (in metric tons) |
|---|---|---|---|
| Western Pacific[1/] | 1948-1958 | 51,680 | 147,433 |
| Central Pacific[2/] | 1948-1959 | 2,767 | 6,348 |
| Eastern Pacific[3/] | 1948-1960 | 27,900 | 80,550 |

On the basis of these figures, the population may vary three-hold, however, this may be used only as a very gross estimate, for changes in fishing effort and in the environment are known to be factors affecting the annual catch.

1/ Japan, Agriculture, Forestry, and Fishery Statistics Bulletins, No. 28, No. 30, and No. 33.

2/ Seckel and Waldon, 1960.

3/ Schaefer, Milner B., 1961.

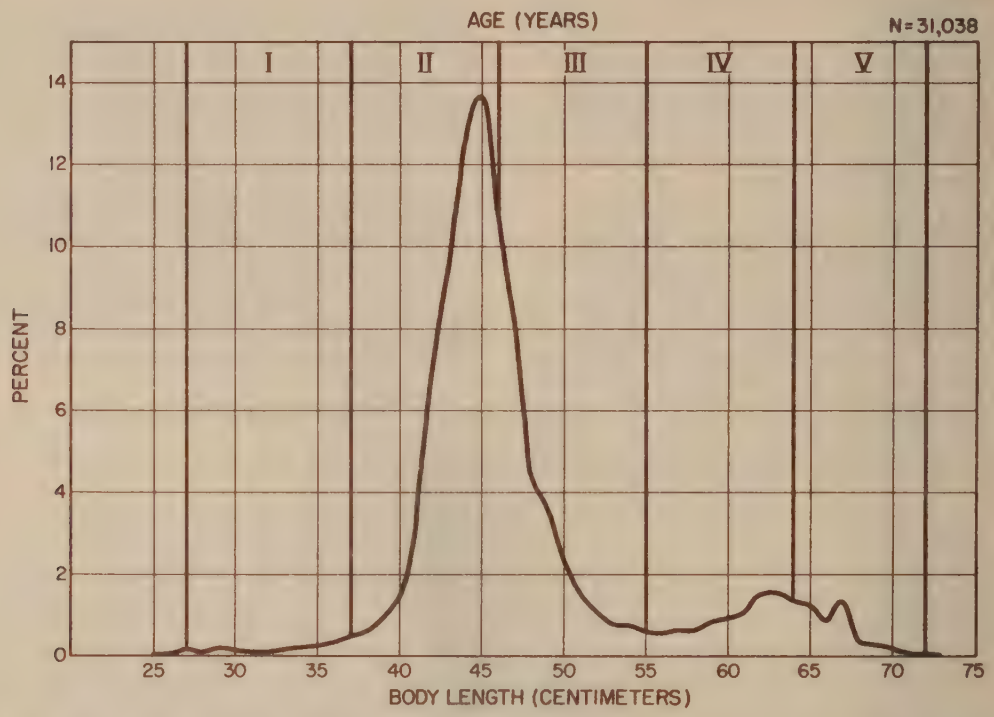


Fig. 9 Size composition of the commercial landings of skipjack in the Japanese fishery (from Kawasaki, 1955a, 1955b)

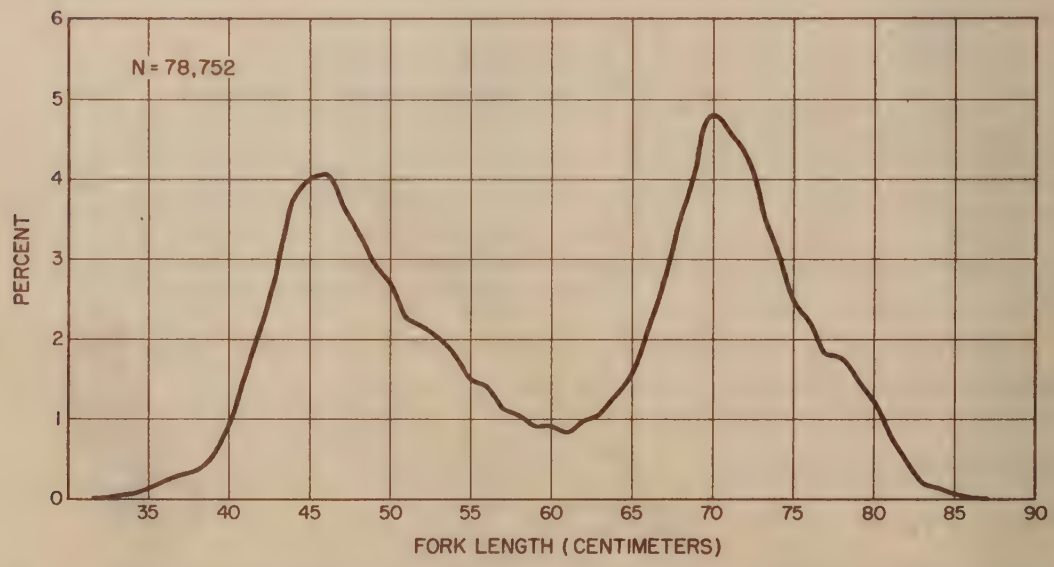


Fig. 10 Size composition of the commercial landings of skipjack in the Hawaiian fishery (from data files, Bureau of Commercial Fisheries, Biological Laboratory, Honolulu)

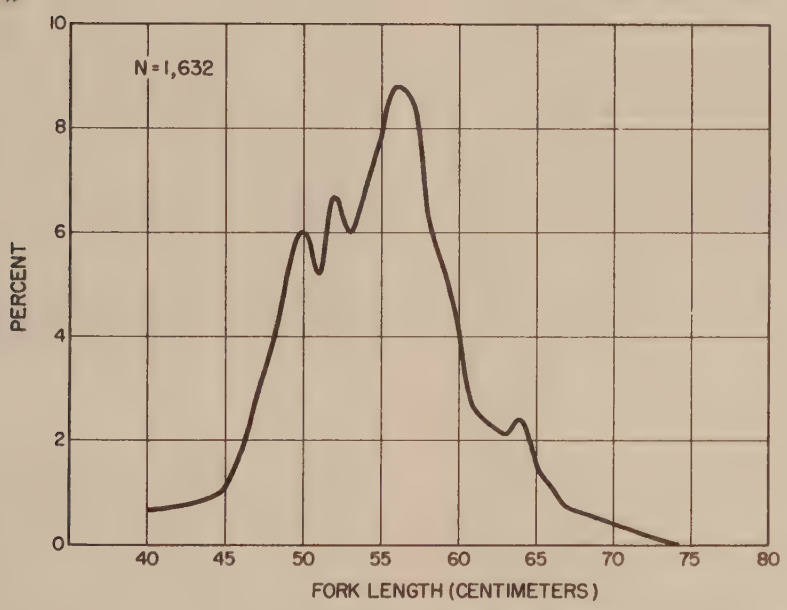


Fig. 11 Size composition of the commercial landings of skipjack in the eastern Pacific fisheries (from Broadhead and Orange, 1960)

## 4.4 Mortality, morbidity

### 4.4.1 Rates of mortality

Schaefer (1960), on the basis of the decline in rate of recovery of tagged skipjack in the eastern Pacific, states that the "annual attrition" rate for skipjack is 98.2 percent during a period of a year and a half after tagging. Schaefer, Chatwin, and Broadhead (1961) computed survival, on the basis of tag recovery data, and in their table 17 show annual survival rates of from 0.056 to 0.349. However, they point out that these rates are only for "survival of skipjack while in the area of the fishery," and that the survival in the whole population will be higher.

## 4.6 Relation of population to community and ecosystem, biological production, etc.

Within the marine community the skipjack may be listed both as prey and predator, although as a large adult it may be only one step removed from a climax predator. In its larval and juvenile stages it serves as food for larger fish, including adult skipjack. As an adult it serves as food for larger tunas and spearfishes, and at the same time preys upon small to moderate-sized pelagic crustaceans, molluscs, and fish. Skipjack compete for food with tunas and other fish of similar size and habits. They might even be considered as competing with sea birds, for the food organisms are often apparently driven to the surface of the water, where they are preyed upon by both skipjack and various sea birds.

Lacking estimates of the population size it is not possible to estimate the biological production of skipjack of the Pacific.

# 5 EXPLOITATION

## 5.1 Fishing equipment

### 5.1.1 Fishing gear

The greatest portion of the skipjack catch of the world is taken by two methods, (1) pole-and-line angling or live-bait fishing, and (2) purse seining.

In the largest fishery, that in Japanese waters, pole-and-line catches accounted for 90-95 percent of the landings and purse-seine catches for less than 10 percent during 1954-58. Set nets and various other types of angling accounted for 1 or 2 percent of the landings. Types of gear which contributed less than 1 percent to the landings included trawls, surround nets (other than purse seines), lift nets, gill nets, longlines, beach seines, and boat seines (Jap. Min. Agricul. For.,1955-1960).

During the past 2 or 3 years there has been an increase in the use of purse seines to take skipjack in the Japanese fishery. Prior to 1958 about 5 percent of the skipjack landed were caught by this method, but in 1958 and 1959, 7 and 10 percent of the skipjack landed were caught by purse seines.

In the American fishery of the eastern Pacific all skipjack landed are taken either by pole-and-line or by purse seines. Over the period 1948 to 1959 between 87 and 96 percent of skipjack in the American fishery were caught by pole-and-line angling and the remainder by purse seines. Beginning in 1959 a much greater use was made of purse seines in the tuna fishery, and by 1960 only 75 percent of the skipjack catch was taken by pole-and-line angling, with 25 percent being taken by purse-seine fishing (Schaefer, 1961).

In the central Pacific Hawaiian fishery practically all skipjack are caught by pole-and-line fishing. A very small amount is caught by trolling and by longline gear.

### 5.1.2 Fishing boats

Boats utilized in fishing for skipjack fall into three types according to the method used to capture the fish, i.e., (1) live-bait boats used in the pole-and-line fishery, (2) purse-seine boats, and (3) miscellaneous boats. This last group consists of boats employed mainly in fisheries catching species other than skipjack but which occasionally capture skipjack, e.g., longline vessels used in the fishery for large tunas.

Live-bait, pole-and-line vessels vary in size and design, but have a common feature, viz., wells or tanks in which live-bait fishes are carried. Those used in the American fishery of the eastern Pacific, commonly called "tuna clippers," have been described by Godsil (1938). Descriptions of newer boats can be found in trade journals and other fishery publications (Anon., 1955a; Anon., 1955b; Hanson, 1955; McNeely, 1961; Petrich, 1955). As described by Godsil (1938), tuna clippers ranged in length from 90 to 180 feet in length, had a carrying capacity of 150 to 350 short tons of frozen tuna, an operating range of 6,000 to 8,000 miles, and carried a crew of 12 to 20 fishermen.

Boats used in the Japanese pole-and-line fishery for skipjack have been described by Takagi (1955), Muramatsu (1960), and Cleaver and Shimada (1950). The deck design of Japanese vessels engaged in this fishery is different from that found in the American fleet, the most noticeable difference being that fishing racks may extend completely around the Japanese boats while in the American boats these racks are confined to the stern and the port quarter. Another difference is that with vessels of comparable length, the Japanese carry a much larger crew, up to 60 men on a 90-foot vessel.

Live-bait boats used in Hawaiian waters are generally smaller than those found in the other fisheries, and have been described by June (1951) and Yamashita (1958). While the hull design resembles the sampans of Japan, the fishing takes place only at the stern as in the American vessels.

Purse-seine vessels engaged in skipjack fishing are found mainly in the American fishery, although they are also used in the Japanese fishery. Scofield (1951) and McNeely (1961) have described the vessels and nets used in the American fishery. The latter author gives an especially detailed description of the conversion of the tuna clippers or live-bait boats to purse seiners, a movement which

began in 1957 and progressed rapidly from that time to the present (1962).

Description of purse seiners used in the Japanese fishery may be found in a publication entitled "Illustrations of Japanese Fishery Boat and Fishing Gear" (Anon., 1958).

An adequate knowledge of the types of vessels and gear used in different fisheries is necessary in understanding fluctuations in catches, which in turn may be used to deduce certain characteristics of the populations. For example, Schaefer (1961) points out that increased use of purse seining in the American fishery has resulted in a decrease in the landings of skipjack, probably not because of a decrease in abundance of skipjack, but because skipjack are not as readily taken by seining as by pole-and-line angling. Shimada and Schaefer (1956) in their study of the American bait-boat fleet found that fishermen using smaller vessels were not selective between skipjack and yellowfin, but that fishermen using larger vessels were selecting yellowfin tuna when this species was readily available. They also showed that it was necessary to adjust catches to a standard size boat in studies of catch and effort. Other considerations, especially when comparing landings by bait boats and purse seiners are: (1) Because the range is not restricted by need for bait, purse seiners may fish more intensively in areas distant from baiting grounds than could bait boats; (2) however, as inferred by Schaefer (1961), because of environmental conditions and behavioral characteristics of skipjack, purse seiners may not be able to fish in areas fished successfully by bait boats.

## 5.2 Fishing areas

### 5.2.1 General geographic distribution

Fig. 4 shows areas of the Pacific in which skipjack are caught in commercial fisheries, while Table XI lists certain of these fisheries.

Skipjack are also taken incidentally by Japanese longline vessels fishing in large areas of the North and South Pacific, by Australian fishermen, and in various subsistence fisheries of Micronesia, Melanesia, and Polynesia.

Prior to World War II considerable quantities of skipjack, as much as 33,000 tons in 1937, (Shapiro, 1948) were landed in the Marshall, Caroline, and Marianas Is.

Table XI
Major commercial skipjack fisheries of the world

| Location | General limits Lat. and Long. | Approximate area in sq. naut. mi. | Number of vessels |
|---|---|---|---|
| Western Pacific (Japanese) | Lat. 18° N - 45° N<br>Long. 120° E - 153° E | 800,000 | 4490 (2927 < 3 tons) Jap. Min. Agric. For. 1959) |
| Central Pacific (Hawaiian) | Lat. 18° N - 23° N<br>Long. 154° W - 161° W | 80,000 | 21 (BLH files 1961) |
| Eastern Pacific (mostly U.S. and Peru) | Lat. 12° S - 34° N<br>Long. 77° W - 128° W | 1-1/2 mil. sq. mi. | 153 (1961, Pac. Fish.) |

5.2.2 Geographical ranges (latitudes, distance from the coast, etc.)

The latitudinal limits of the major fisheries are given in Table XI above, as well as the area covered by the fishery. As can be seen from Fig. 4, most of the fisheries operate within a few hundred miles of land. Even the large Japanese and American fisheries in the Pacific, although they cover over 1,500 and 2,500 miles respectively in a north-south direction, extend only 200-300 miles offshore. This situation may be a reflection of the method of capture more than the distribution of skipjack, i.e., live bait, obtainable only at inshore localities, is used in the capture of most of the skipjack, the major exception being the purse-seine methods used in the American and Japanese fisheries.

5.2.3 Depth ranges

All live-bait fisheries for skipjack are prosecuted at the immediate surface of the sea. Purse seines are essentially surface gear although the fish may be captured at a deeper level than in the live-bait fishery. Skipjack are also taken on longlines fishing at depths up to a few hundred feet, but this gear is used primarily for larger tunas and the skipjack catch is incidental to that of other tunas such as yellowfin and bigeye. Further, it has not been shown whether skipjack taken on longlines are actually caught at a depth, or at the surface while the longline gear is being set or retrieved.

5.3 Fishing seasons

5.3.1 General pattern of fishing seasons

Perhaps because of the relatively slight seasonal change in their environment, skipjack tend to be fished throughout the year. The period during which the majority of the catch is landed is seasonal in most fisheries, however, and usually occurs during the summer. Thus in the Northern Hemisphere the season usually includes the months of June, July, and August, while in the Southern Hemisphere the season includes January, February, and March. At the northern and southern limits of the fisheries the seasons tend to occur more nearly in mid-summer, while near the center of the range, i.e., in the equatorial areas, the season may include a longer time period.

5.3.2 Duration of fishing season

In any one locality the season may last for only a few months, and in fisheries which have wide latitudinal ranges it is necessary to examine the catch by area or region to determine the duration of the season. Table XII shows certain data concerning fishing seasons for the Japanese, American, and Hawaiian fisheries.

In the Hawaiian fishery, which covers only a small area (see Section 5.2.2, Fig. 4), catch statistics show a season of only about 5 months, during which time 75 percent of the annual catch is landed.

In the American fishery, extending from latitude 34° N to 12° S, it is difficult to define seasons. Alverson (1959) shows catch by quarter for the years 1952-1955 for nine regions of the fishery. An examination of his table 4 indicates that the season at the extremes of the fishery, i.e., off Baja California and the regions off South America, lasts about 3 months, while in the Central American region the season is less marked but may persist over a 6-month period (Table XII).

In the Japanese fishery, Imamura (1949) states that the duration of the season may vary from throughout the year in the South Seas Area and off Taiwan to only 6 months in the Kinan area near Japan. An examination of the monthly landings (Jap. Min. Agricul. For., 1955-1960) shows that the months of above-average landings are from April to October, or 7 months.

5.3.3 Date of beginning, peak, and end of season

Table XII lists these data for the Japanese, Hawaiian, and American fisheries.

5.3.4 Variation in time or duration of fishing season

In the Hawaiian fishery the season may begin as early as March or as late as May, and may end from September to November inclusive. The peak month is usually July, sometimes June, and rarely August.

Table XII
Time and duration of the skipjack fishing seasons in the Pacific

| Area and region | Start of season | End of season | Peak of season |
|---|---|---|---|
| Eastern Pacific 1/ | | | |
| Baja California | | | July to September |
| Revillagigedos | | | April to June |
| Gulf of California | | | October to December |
| Gulf of Tehuantepec | | | April to June |
| Central America | | | April to September |
| Gulf of Panama | | | April to June |
| Malpelo Is. | | | April to September |
| Northern South America | | | October to December |
| Galapagos Is. | | | October to March |
| Central Pacific 2/ | May | September | July |
| Western Pacific 3/ | | | |
| Taiwan | Throughout the year | | |
| South Seas Area | Throughout the year | | |
| Satsunan Area | February | November | June-July |
| Kinan Area | March | August | April-June |
| Zunan Area | March | October | June-July |
| Northeastern Sea Area | April | October | July-August |

1/ After Alverson (1959). The season for this area can be defined only by quarters of the year.
2/ Yamashita (1958)
3/ Imamura (1949)

In the Japanese fishery the greatest variation in the season occurs in the portion of the fishery north of about latitude 35° N, known as the Northeastern Sea Area. Here the fishery may begin as early as April or as late as July, and may terminate between late August and early October (Kimura, 1949).

In the eastern Pacific fishery enough variation in catch occurs so that landings summarized by quarters of the year are sufficient to show gross seasonal changes. As shown by Alverson (1959, his table 4) the peak catches may occur in the Revillagigedos, the Gulf of Tehuantepec, and the Gulf of California regions during the second or fourth quarters. The regions off Central America, the Gulf of Panama, and Malpelo Is. may have peak catches in either the second or third quarters. In the Galapagos Is. region peak catches occur in either the first or fourth quarters. Only off Baja California and the coasts of northern South America do peak catches consistently occur during the same quarter from year to year (at least in the available data), the third quarter for the former and the fourth quarter for the latter.

### 5.3.5 Factors affecting fishing season

In the eastern Pacific fishery economic factors influence the landings of skipjack to a certain extent. Yellowfin tuna command a higher price generally, and when this species is readily available less effort may be expended by fishermen, especially by those with larger boats, on skipjack than when yellowfin are less available (Shimada and Schaefer, 1956). Further, when the price received by the fishermen drops below a certain point the total fishing effort decreases. Thus, decreases in skipjack landings may

reflect a decrease in total fishing effort, a decrease in the effort expended on skipjack, a decrease in availability of skipjack, or a combination of two or more of these factors.

Ecological factors also affect the onset, success, and termination of the skipjack fishing season in certain areas of the eastern Pacific, particularly in the northern and southern limits of the fishery. Blackburn (1961) indicates that skipjack are sufficiently plentiful to support a fishery off northern Baja California and northern Chile and southern Peru during years when seas surface temperatures approach 21° C or greater. In addition to changes in the fishery induced by what might be termed normal movements of certain isotherms, there is the "El Niño" phenomenon occurring off the coasts of Chile and Peru, and when this phenomenon is quite marked, skipjack are more widely scattered and may be found further south than in the so-called normal years (Schaefer, 1961b). Blackburn (1960) also points out that in certain localities off southern Mexico and Central America a season for skipjack may fail to develop in years when sea surface temperatures reach 28° C or greater.

In the Japanese fishery both economic and environmental factors may contribute to variation in the onset, success, and termination of the season. Kimura (1949) has described the acceleration or delay in the onset of the season, especially in the Northeastern Sea Area, in response to changes in the flow of the Kuroshio and Oyashio current systems. A strong, northward flowing Kuroshio (warm water) early in the season will in general accelerate the onset of the fishing season. Conversely a weak Kuroshio or the late development of a strong Kuroshio, or a strong Oyashio (cold water) will delay the onset of the season. An early termination of the season occurs when there is an early weakening of the Kuroshio or strengthening of the Oyashio. Conversely a late weakening of the Kuroshio or strengthening of the Oyashio will result in a prolonged season. Imamura (1949), Sasaki (1939), Shapiro (1948), Cleaver and Shimada (1950), and Kawasaki (1955a, 1955b) also mention the dependence of the season development on the flow of the Kuroshio and Oyashio.

Kimura (1949) described years in which skipjack fishing began late in the season because of the availability to the fishery of large quantities of albacore.

In the Hawaiian fishery variations in the season appear to be almost entirely attributable to changes in the environment (Seckel and Waldron, 1960). The advent of the season in this area appears to depend upon the movement into the Hawaiian area of waters of the California Current extension having a salinity somewhat lower than that of the waters of the Kuroshio Current extension which generally cover the area during the off season period. The success of the season also appears to depend upon an early northward movement of the California Current extension waters. The beginning of this northward movement is reflected in a change from cooling to warming of the surface waters in the vicinity of the Hawaiian Is. early in the year. When this warming occurs before the first of March a better than average season ensues, and when the warming is delayed until after the first of March a poorer than average season can be expected. The basic reasons for this association are not known.

## 5.4 Fishing operations and results

### 5.4.1 Effort and intensity

For the eastern Pacific fishery Shimada and Schaefer (1956) have computed the relative fishing intensity in terms of fishing days for a standard size bait boat (i.e., pole-and-line fishing vessel) over the period 1934-1954, and Schaefer (1961) has extended this to include 1960. During that period there was a gradual, though fluctuating, increase in intensity from 5,939 days in 1934 to about 39,000 days in 1958 followed by a decrease to about 29,000 days in 1960. The catch per standard day's fishing (for class 3 boats, which have a fish-carrying capacity of 101 to 200 short tons, about 97 to 182 metric tons) varied between about 1.0 and 3.1 metric tons over the period 1934 to 1954.

During this period the number of vessels engaged in the fishery increased from 61 bait boats in 1934 to 225 in 1951 followed by a decrease to 182 in 1954. The number of purse seiners increased from 9 in 1934 to 89 in 1948 followed by a decrease to 69 in 1954. Since 1954 the number of bait boats has decreased sharply to only 48 in 1961, while the number of purse

seiners has increased to 98 (McNeely, 1961). This is largely due to the conversion of bait boats to large purse seiners during 1958 to 1961.

Alverson (1960) summarized the fishing effort and catch in the eastern Pacific by quarters of the year and by one-degree squares for 1952-1958 but did not compute the relative intensity as did Shimada and Schaefer (1956).

It is difficult to assess the fishing effort and intensity in the Japanese fishery. The annual catch statistics for 1959 (Jap. Min. Agricul. For., 1960) give some idea of the effort and how it differs from the present American fishery. The Japanese skipjack pole-and-line fishery in 1959 was made up of about 4,490 vessels, of which 76 percent were vessels classed as less than 5 metric tons, 12.5 percent as 5 to 50 tons, and 11.5 percent as 50 to 500 tons. In 1959 these groups of vessels landed 5, 20, and 75 percent respectively of the total catch by the skipjack pole-and-line fishery during a total of 235,000 vessel-days of fishing. Catch per unit per day was 0.096, 0.675, and 1.775 metric tons for the < 5, 5 to 50, and 50 to 500 ton vessels respectively.

Relative intensity and effort in terms of days for a standard size vessel have not been computed for the Japanese fishery.

Yamashita (1958) described the Hawaiian skipjack fishery for the period 1944 to 1953; during that period there was a maximum of 28 full-time skipjack vessels. At present (1962) the Hawaiian fishery is prosecuted by 21 full-time pole-and-line vessels of about 15 to 50 net tons capacity. During 1,646 days of fishing per year this fleet landed about 4,500 metric tons of skipjack, or about 2.7 metric tons per vessel per successful day of fishing (unpublished data in BLH files) for the period 1952-60.

### 5.4.2 Selectivity

Two types of selectivity affect the sizes of skipjack taken in the different fisheries, (1) gear selectivity and (2) economic selectivity. Because of variations in types of gear, construction of gear, and the economy associated with different fisheries, the effect of these two types of selectivity is not always the same in different areas.

The pole-and-line fishery in Japanese waters takes skipjack from 22 cm fork length up to the maximum sizes available (Kuronuma, Kafuku, and Kikawa, 1949). Skipjack below 30 cm do not appear to be abundant in the catches as a whole, but considerable numbers may be taken on occasions. In the eastern Pacific skipjack less than 40 cm fork length are uncommon in the catch, and in the central Pacific those below 35 cm are seldom caught.

On the basis of the above information it appears that commercial pole-and-line gear selects only fish above 22 cm, and in fact rarely captures skipjack below 30 cm in length. Variations in gear characteristics, e.g., small vs. large hooks, light vs. heavy poles, etc., may account for the difference in minimum size of skipjack caught in the western, central, and eastern Pacific.

No information is available concerning the degree of selectivity for fish above the minimum size captured, although it is likely that such a selectivity does exist. However, it seems unlikely that gear selectivity is a factor for skipjack above about 45 cm length (1.9 kg wt ) in any of the fisheries.

Economic selectivity is a factor restricting the capture of certain sizes of skipjack in the central Pacific, and probably in the eastern Pacific fisheries. Economic selectivity becomes effective when buyers refuse to accept skipjack below certain sizes, and when this occurs fishermen usually refrain from catching fish of or below this size. In the Hawaiian fishery, for example, skipjack below about 4 pounds are often not acceptable to the cannery, the major market during the season. In the eastern Pacific fishery the smaller skipjack often can be sold only at a price lower than that obtainable for the more desirable sizes. In addition to a price differential, a minimum legal size limit of 4 pounds (= 1.8 kg ) or about 45 cm may control the minimum size of fish landed in the eastern Pacific fisheries (Schaefer, 1961). It is not known whether economic selectivity affects the catch or skipjack in the Japanese fishery, which has a much more varied market for its catch than do the central and eastern Pacific fisheries. It is quite likely that when albacore are available in large numbers, fishermen may select albacore in preference to skipjack.

5.4.3 Catches

Annual catches for the 25-year period 1935 to 1959 are listed in Table XIII and shown in Fig. 12 for the Japanese, Hawaiian, and eastern Pacific fisheries. It should be noted that the low landings for the period 1941 to about 1950 reflect changes in fishing effort due to wartime restrictions rather than changes in abundance of skipjack. This is true for all three areas of the Pacific.

It is difficult to apportion the eastern Pacific catch among the fisheries of the different countries. The FAO catch statistics for 1959 (FAO, 1960) lists skipjack landings for Mexico between 1955 and 1957, and for Peru between 1954 and 1958. However, the FAO total for the U.S., Peru, and Mexico is between 1 percent and 12 percent less than the total for the eastern Pacific listed by Schaefer (1961) for that period. It is probable that this difference is due to landings in other Central and South American countries which are not reported in the FAO summary.

The figures in Table XIII for the western Pacific are only for the Japanese skipjack landings. Other countries, including the Philippines, Australia, Korea, and Taiwan land skipjack but figures for these landings are not easily accessible because they are included in total tuna landings.

In the central Pacific, in addition to the Hawaiian fishery, there are smaller subsistence fisheries throughout the general area of Polynesia, Micronesia, and Melanesia. Skipjack are occasionally caught in the longline fishery for albacore and yellowfin in the South Pacific, but the amount of these catches is usually not included in the landings. Such catches could be considered as part of the subsistence catches, and do not reflect in any way the abundance of skipjack.

Average monthly catches for the Japanese, Hawaiian,and part of the eastern Pacific fisheries are given in Table XIV and shown in Fig. 13. The eastern Pacific landings include only those landed in or shipped into the State of California, and therefore do not equal the total eastern Pacific landings, although they include the major portion. The distinct seasonal nature of the western and central Pacific fisheries is quite apparent from this table, and it is equally apparent that the eastern Pacific landings are less seasonal.

5.5 Fisheries management and regulations

Very few regulations or management procedures affect the skipjack fisheries of the Pacific. Only in the eastern Pacific is there a legal minimum size, which as mentioned earlier is 4 pounds (= 1.8 kg or about 45 cm length). The only other limitation as to minimum size is either the refusal of processors to accept skipjack below certain sizes or to accept them at a lower price.

5.6 Fish farming, transplanting, and other intervention

Operations of this nature are not carried out with skipjack.

Table XIV
Average monthly landings of skipjack in metric tons

| | Japan 1955-59 | California 1955-59 | Hawaii 1948-60 |
|---|---|---|---|
| January | 421 | 5,329 | 123 |
| February | 1,006 | 4,458 | 81 |
| March | 3,206 | 3,869 | 121 |
| April | 8,718 | 4,559 | 245 |
| May | 19,133 | 4,106 | 485 |
| June | 19,463 | 5,283 | 743 |
| July | 27,138 | 5,506 | 878 |
| August | 16,712 | 6,139 | 773 |
| September | 13,222 | 5,548 | 455 |
| October | 9,339 | 5,035 | 301 |
| November | 2,386 | 5,376 | 152 |
| December | 1,051 | 4,776 | 103 |

Table XIII
Landings of skipjack in the Pacific area 1935 to 1959, in metric tons
(one metric ton = 2,205 pounds or one metric ton = 266.7 kan)

| | Japan 1/ | Eastern Pacific 2, 3/ | Hawaii 4/ | Total Pacific | Mexico 5/ | Peru 5/ | Ryukyus 5/ |
|---|---|---|---|---|---|---|---|
| 1935 | 72,881 | 7,799 | 2,210 | 82,890 | | | |
| 1936 | 101,032 | 12,247 | 3,507 | 116,786 | | | |
| 1937 | 105,907 | 21,362 | 5,799 | 133,068 | | | |
| 1938 | 120,813 | 10,274 | 4,409 | 135,496 | | | |
| 1939 | 100,518 | 13,660 | 3,902 | 118,080 | | | |
| 1940 | 116,346 | 26,113 | 6,086 | 148,545 | | | |
| 1941 | 91,627 | 11,690 | 1,656 | 104,973 | | | |
| 1942 | 79,713 | 17,681 | 5 | 97,399 | | | |
| 1943 | 51,690 | 13,347 | - | 65,037 | | | |
| 1944 | 48,400 | 14,124 | 333 | 62,857 | | | |
| 1945 | 17,800 | 15,435 | 1,772 | 35,007 | | | |
| 1946 | 41,450 | 19,252 | 2,553 | 63,255 | | | |
| 1947 | 48,700 | 24,255 | 2,536 | 75,491 | | | |
| 1948 | 40,700 | 27,880 | 3,802 | 72,382 | | | |
| 1949 | 46,450 | 36,742 | 4,487 | 87,679 | | | |
| 1950 | 84,550 | 58,623 | 4,313 | 147,486 | These are included in the eastern Pacific totals. | | |
| 1951 | 104,300 | 54,937 | 5,862 | 165,099 | | | |
| 1952 | 85,951 | 41,171 | 3,307 | 130,429 | | | |
| 1953 | 72,701 | 60,614 | 5,469 | 138,784 | | | |
| 1954 | 99,829 | 78,790 | 6,359 | 184,978 | | 7,700 | 6,100 |
| 1955 | 99,654 | 58,049 | 4,397 | 162,100 | 300 | 7,600 | 3,900 |
| 1956 | 97,990 | 68,163 | 5,048 | 171,201 | 500 | 9,600 | 5,000 |
| 1957 | 97,463 | 58,185 | 2,780 | 158,428 | 100 | 10,300 | 4,900 |
| 1958 | 147,433 | 74,784 | 3,099 | 225,316 | | 13,200 | 7,100 |
| 1959 | 166,707 | 80,543 | 5,629 | 252,879 | | | 10,800 |

1/ Japanese fishery statistics: 1335-1945 Espenshade, 1948
1946-1959 Japanese Ministry of Agriculture and Forestry for the years 1951, 1954-1959

2/ Eastern Pacific fishery statistics: 1935-1954 Shimada and Schaefer, 1956
1955-1959 Schaefer, 1961

3/ The eastern Pacific landings include those of Peru.

4/ Hawaiian fishery statistics: 1935-1953 Yamashita, 1958
1954-1959 Files of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu

5/ FAO (1960) Yearbook of Fishery Statistics for 1959, vol. 11

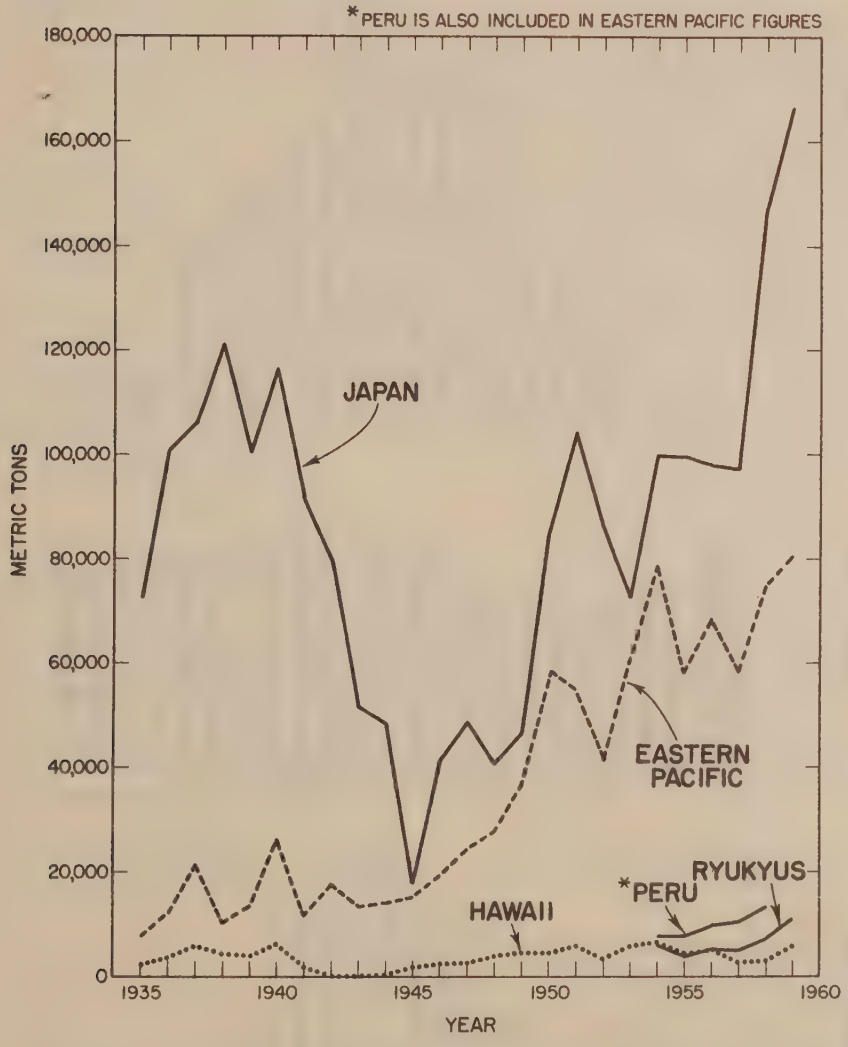


Fig. 12 Annual skipjack landings during the period 1935 to 1959 for the Japanese, Hawaiian, and eastern Pacific fisheries

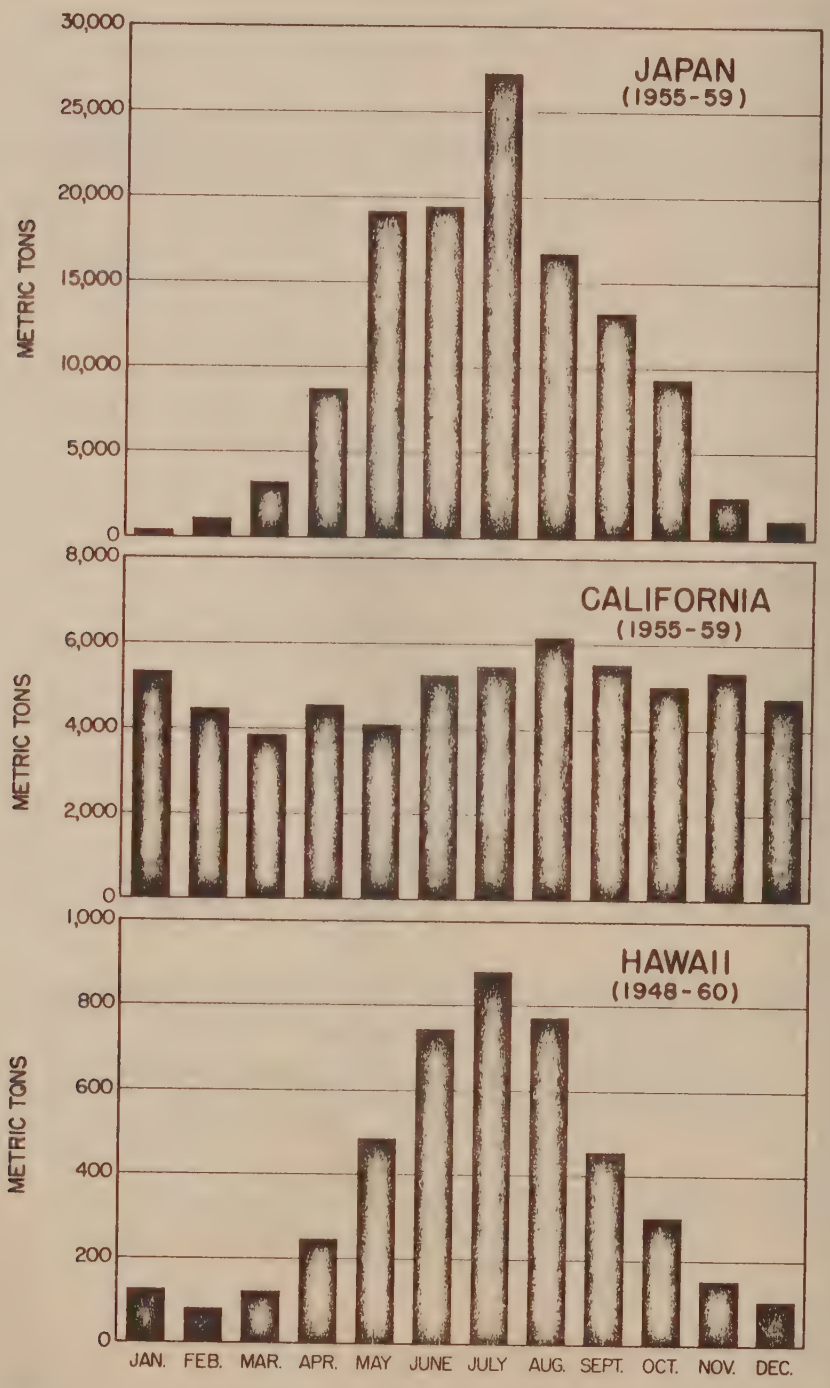


**Fig. 13** Mean monthly landings of skipjack in Japan, Hawäii, and California for the period 1955 to 1959

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Experience Paper No. 26

# FOOD OF SKIPJACK IN THE CENTRAL PACIFIC

By

KENNETH D. WALDRON and JOSEPH E. KING
U.S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

## Abstract

An examination of the stomach contents of 707 skipjack from waters near the Hawaiian, Line, and Phoenix Islands showed that by volume the food consisted of 3.7 percent crustaceans, 19.9 percent molluscs, 74.6 percent fish, and 1.8 percent unidentifiable remains. It was found that skipjack consumed more fish and fewer molluscs than did yellowfin and bigeye tuna. Larval and juvenile tuna, mostly skipjack, constituted a high percentage of the food of skipjack. Smaller volumes of stomach contents were found for: (1) troll as compared with pole-and-line caught skipjack, (2) subsurface as compared with surface caught skipjack, and (3) small as compared with large skipjack. Variation in the detailed composition, but not in the major food groups, was associated with: (1) size of skipjack, (2) distance from land, (3) time of capture, and (4) month of capture. Variation in the proportion of the major food groups utilized was associated with area of capture.

# ALIMENTATION DES BONITES A VENTRE RAYE DU PACIFIQUE CENTRAL

## Résumé

L'examen des contenus stomacaux de 707 bonites à ventre rayé provenant des eaux au large de l'archipel des Hawaii et des îles Phoenix et de la Ligne a fourni les pourcentages quantitatifs suivants d'aliments: crustacés, 3,7 pour cent; mollusques, 19,9 pour cent; poissons, 74,6 pour cent; restes non identifiés, 1,8 pour cent. On a constaté que les bonites à ventre rayé consommaient davantage de poissons et moins de mollusques que les thons à nageoires jaunes et les thons obèses. Les stades larvaires et immatures des thons - principalement bonites à ventre rayé - constituent un pourcentage élevé de la

nourriture des bonites à ventre rayé. Le contenu stomacal est moindre dans les cas suivants: 1) bonites à ventre rayé prises à la traîne par rapport à bonites capturées à la canne et à l'hameçon; 2) bonites pêchées en profondeur par rapport à bonites capturées en surface; 3) bonites de petite taille par rapport à bonites de grande taille. Les écarts dans la composition de détail, mais non dans les groupes principaux d'aliments, correspondent aux éléments suivants: 1) taille des bonites; 2) distance de la côte; 3) heure de la capture; 4) mois de la capture. Les variations dans la proportion des principaux groupes d'aliments utilisés sont en rapport avec la zone de pêche.

## LA ALIMENTACION DEL BARRILETE EN EL PACIFICO CENTRAL

Extracto

Un examen del contenido estomacal de 707 barriletes procedentes de aguas próximas a Hawaii, las Espóradas Ecuatoriales y las Islas Phoenix, demostró que, en volumen, el alimento estaba formado por el 3,7 por ciento de crustáceos, 19,9 por ciento de moluscos 74,6 por ciento de peces y 1,8 por ciento de residuos no identificables. Se observó que el barrilete consumía más peces y menos moluscos que el atún de aleta amarilla y el patudo. Un gran tanto por ciento de la alimentación del barrilete estaba constituido por formas larvales y juveniles, en su mayoría de barrilete. Se hallaron contenidos estomacales inferiores para: (1) el barrilete capturado con curricán en relación con el capturado con liña; (2) el barrilete capturado en la subsuperficie frente al capturado en la superficie, y (3) los individuos de pequeño tamaño en comparación con los de gran tamaño. La variación en la composición detallada, aunque no en los grupos principales de alimentos, se asoció a: (1) el tamaño del barrilete; (2) la distancia de tierra; (3) el tiempo de la captura, y (4) el mes de la captura. La variación de las proporciones de los principales grupos de alimentos utilizados se relacionó con los lugares de captura.

## 1 INTRODUCTION

The skipjack, Katsuwonus pelamis (Linnaeus), enjoys a wide distribution in the warmer waters of all oceans and forms the basis for commercial fisheries in certain areas. In the Hawaiian Islands, where the skipjack constitutes 50 to 70 percent of the commercial fish catch, production of this species ranged from 6 to 14 million pounds in the years 1948-1960, and it contributed over a million dollars annually to the economy of the Islands (Yamashita, 1958; U. S. Fish and Wildlife Service, 1961).

In Hawaii, as elsewhere in the Pacific, skipjack are taken principally by live-bait, pole-and-line fishing. The catch displays a marked seasonal variation with a major peak in the mid-summer months. The U. S. Bureau of Commercial Fisheries Biological Laboratory at Honolulu is investigating the interrelationships between skipjack and the environment to learn the causes for the seasonal variation and the factors influencing the day-to-day changes in the distribution of the fish on the fishing grounds.

This present study was undertaken for the purpose of examining more specifically variations in the food of skipjack as related to the time, locality, depth, and method of capture. It was hoped that the resulting information would contribute to a better understanding of the general ecology of the skipjack as well as of the annual and seasonal fluctuations in the catch. Comparisons were made of the food of skipjack with that of yellowfin and bigeye tuna.

The food of skipjack is generally well known as the result of the studies of Suyehiro (1938) and Hotta and Ogawa (1955) in Japanese waters, Welsh (1949) in Hawaiian waters, and Ronquillo (1953) in the Philippines. In addition there are numerous, scattered references in the literature, particularly in reports on the Japanese skipjack fishery, to various items found in the stomach contents. The statement that the food of skipjack consists of "Crustacea, squid, and fish" is frequently made and, in fact, could be applied to the majority of the tunas.

This is the fifth report of the Honolulu Laboratory dealing with the food of tunas in the central Pacific. The others were concerned with the food of yellowfin (Neothunnus macropterus) (Reintjes and King, 1953), with a comparison of the food of bigeye (Parathunnus sibi) and yellowfin (King and Ikehara, 1956), the food of albacore (Thunnus germo) (Iversen, 1961), and the food of skipjack in Marquesan waters (Nakamura, MS).

Thanks are due the officers and crew members of the Laboratory's research vessels and to all scientific personnel who aided in collecting the stomach samples. Also, special recognition should go to I. Ikehara, T. Otsu, T. Roseberry, A. Y. Shimomura, and D. Yamashita who, at one time or another, assisted in the measurement and identification of the stomach contents.

## 2 SOURCE OF MATERIALS

This report is based on an analysis of the stomach contents of skipjack collected during the years 1950-56 on 41 cruises (Table I) of the Bureau of Commercial Fisheries' research vessels Hugh M. Smith, John R. Manning, Charles H. Gilbert, and Henry O'Malley, and of the chartered vessels Cavalieri and Commonwealth. The collections were obtained from areas adjacent to the Hawaiian Islands, the Line Islands, and the Phoenix Islands, and from the intervening waters of the central Pacific (Fig. 1).

Of the 4,690 skipjack caught on these cruises, the stomachs of 707, or 15.1 percent, were preserved for subsequent analysis. Of this total, 587 stomachs were obtained from fish captured on or near the surface (25 by purse seining, 66 by surface trolling, and 496 by live-bait fishing), and 120 stomachs were from fish captured on longlines[1/] fishing at depths from 150 to 500 feet. The sampled fish ranged in size from 33 to 88 cm. (1-1/2 to 38 pounds).

## 3 METHODS

The stomach was removed from the fish at time of capture, placed in a cloth bag, and preserved in 10 percent formalin.

In the laboratory the stomach was slit open and the contents removed, sorted, and identified to the most precise degree practicable. Enumeration and volumetric measurement of each species or group of food organisms were subsequently made and recorded. Material identifiable as parasites, and baits used in the capture of the

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1/ A description of the Laboratory's longline gear is provided by Mann (1955).

Table I

Skipjack catch and stomach collections
by vessel, cruise, cruise period, and fishing method

| Vessel | Cruise No. | Cruise period | Fishing method | Number captured | Number examined | Percent examined |
|---|---|---|---|---|---|---|
| Hugh M. Smith | 2 | Jan.-Feb., 1950 | Trolling | 10 | 9 | 90 |
| | | | Pole-and-line | 10 | 6 | 60 |
| | 4 | May-June, 1950 | Pole-and-line | 150 | 54 | 36 |
| | 5 | July, 1950 | Trolling | 2 | 2 | 100 |
| | 6 | August, 1950 | Trolling | 2 | 2 | 100 |
| | 7 | Oct.-Nov., 1950 | Trolling | 3 | 2 | 67 |
| | | | Longline | 5 | 4 | 80 |
| | 8 | January, 1951 | Trolling | 1 | 1 | 100 |
| | 9 | June, 1951 | Pole-and-line | 28 | 2 | 7 |
| | | | Trolling | 2 | 2 | 100 |
| | 11 | September, 1951 | Longline | 23 | 16 | 70 |
| | 15 | May-June, 1952 | Trolling | 3 | 3 | 100 |
| | 18 | Oct.-Nov., 1952 | Longline | 14 | 6 | 43 |
| | 22 | September, 1953 | Pole-and-line | 276 | 60 | 22 |
| | 26 | May-June, 1954 | Pole-and-line | 159 | 30 | 19 |
| | | | Trolling | 3 | 3 | 100 |
| | 28 | Mar.-April, 1955 | Pole-and-line | 122 | 12 | 10 |
| | | | Trolling | 3 | 3 | 100 |
| | 29 | June, 1955 | Longline | 1 | 1 | 100 |
| | 31 | November, 1955 | Trolling | 2 | 1 | 50 |
| John R. Manning | 2 | April-May, 1950 | Trolling | 20 | 16 | 80 |
| | 3 | September, 1950 | Trolling | 1 | 1 | 100 |
| | 4 | November, 1950 | Trolling | 6 | 5 | 83 |
| | 7B-C | Aug.-Sept., 1951 | Purse seine | 516 | 25 | 5 |
| | 11 | Feb.-Mar., 1952 | Longline | 17 | 6 | 35 |
| | 13 | November, 1952 | Longline | 26 | 2 | 8 |
| | 14 | Feb.-Mar., 1953 | Longline | 30 | 15 | 50 |
| | 15 | May, 1953 | Longline | 15 | 6 | 40 |
| | 16 | August, 1953 | Longline | 15 | 10 | 67 |
| | 18 | December, 1953 | Longline | 6 | 5 | 83 |
| | 19 | January, 1954 | Longline | 4 | 4 | 100 |
| | 20 | June, 1954 | Longline | 9 | 9 | 100 |
| | 28 | June, 1955 | Longline | 3 | 3 | 100 |
| | | | Trolling | 1 | 1 | 100 |
| | 29 | Jan.-Feb., 1956 | Longline | 7 | 2 | 29 |
| | | | Trolling | 6 | 1 | 17 |
| Henry O'Malley | 3 | May, 1950 | Pole-and-line | 18 | 4 | 22 |
| | 4 | July, 1950 | Trolling | 7 | 3 | 43 |
| | | | Pole-and-line | 9 | 5 | 56 |
| Cavalieri | 1 | Aug.-Sept., 1950 | Longline | 29 | 14 | 48 |
| Charles H. Gilbert | 7 | February, 1953 | Trolling | 2 | 2 | 100 |
| | 12 | May, 1953 | Pole-and-line | 35 | 5 | 14 |
| | 15 | Mar.-April, 1954 | Longline | 18 | 7 | 39 |
| | 16 | July-Aug., 1954 | Pole-and-line | 591 | 63 | 11 |
| | | | Trolling | 1 | 1 | 100 |
| | 19 | February, 1955 | Pole-and-line | 1 | 1 | 100 |
| | | | Trolling | 16 | 2 | 12 |

Table I (con.)

Skipjack catch and stomach collections
by vessel, cruise, cruise period, and fishing method

| Vessel | Cruise No. | Cruise period | Fishing method | Number captured | Number examined | Percent examined |
|---|---|---|---|---|---|---|
| Charles H. Gilbert-(con.) | 21 | May-June-Jul., 1955 | Pole-and-line | 986 | 99 | 10 |
| | | Jul.-Aug., 1955 | Pole-and-line | 1460 | 155 | 11 |
| | | | Trolling | 1 | 1 | 100 |
| | 23 | Sept.-Oct., 1955 | Trolling | 5 | 5 | 100 |
| | | | Longline | 1 | 1 | 100 |
| | 25 | Jan.-Feb., 1956 | Longline | 5 | 5 | 100 |
| Commonwealth | 4 | July, 1955 | Longline | 4 | 4 | 100 |
| TOTAL | | | | 4690 | 707 | Avg. 15.1 |

fish were omitted from the final analysis. In many instances the stomachs contained small amounts of unidentifiable, amorphous material which was listed as "unidentified remains." This material has been included in the final analysis, but it is relatively small in volume and should not distort the results.

The methods and literature used in the identification of the food organisms were essentially the same as those employed by Reintjes and King (1953) and will not be reviewed here. Berg's (1947) system of classification and nomenclature was used for the family names of the forage fishes, except where other names appeared to be more acceptable.

Three basic criteria were used to assess the importance of the various food items; these were the number of such organisms, their volume, and their frequency of occurrence, indicating, respectively, their general abundance, relative food value, and availability. Appendix Table I contains a list of all the food organisms found in the skipjack stomachs. For each food element there is indicated the total number of each item, the number of stomachs in which it was found, its percentage of occurrence, the total volume of each item, and its percentage of the total aggregate volume.

Because of the great variability in the data, and for other reasons explained by King and Ikehara (1956), no attempt has been made to apply statistical tests. The conclusions, therefore, are based on average values with no appraisal of their statistical significance. Sampling has been extensive, however, and it is not likely that the conclusions would be greatly modified by further observations.

When a general index of importance was needed, e.g. in evaluating the importance of different fish families, the items were ranked in descending order of total number, frequency of occurrence, and volume. These ranks were then summed and an overall rank for each item obtained.

## 4 RESULTS

It is difficult to make proper comparisons of the foods of skipjack, yellowfin, and bigeye tunas since the specimens of these fishes from which stomach samples were obtained differ greatly in size and have somewhat different vertical and horizontal distributions (Brock, 1949; Nakamura, 1949; Murphy and Shomura, 1953a, 1953b). Skipjack, with a maximum size of about 50 pounds, are taken principally on the surface and are found in coastal and oceanic waters; yellowfin reach a maximum of about 200 pounds and are taken from inshore and open ocean areas; bigeye reach a maximum of about 300 pounds, are usually taken well below the surface on longline, and are strictly oceanic. Differences in the food of yellowfin and bigeye, as related to the depth and distance of capture from land, have been discussed previously (Reintjes and King, 1953; King and Ikehara, 1956).

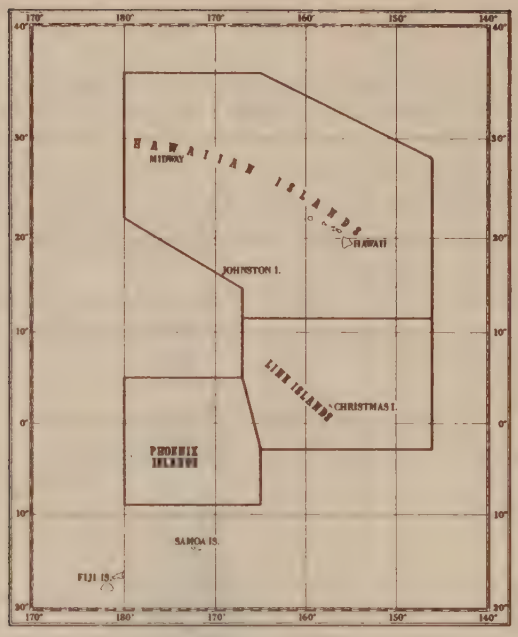


Fig. 1 Area of the central Pacific from which the skipjack stomach collections were obtained.

Fig. 2 Percentage frequency of occurrence of the major groups of food organisms for skipjack, yellowfin, and bigeye tuna.

The food of skipjack includes a wide variety of organisms representing 11 invertebrate orders and 42 fish families (Appendix Table I). In respect to the consumption of the major food categories, fish occurred in 67 percent of the stomachs, Crustacea in 36 percent, and squid in 35 percent (Fig. 2). Those fish families ranking highest in frequency of occurrence were Gempylidae, Scombridae, Mullidae, Chaetodontidae, and Holocentridae (Table II). The first two of these families are fishes of the open ocean, while the last three families are primarily fishes of the reef, lagoon, and other coastal waters. However, a considerable proportion of the members of these three families were larval and juvenile forms often found in an oceanic environment some distance from shore. The reef-frequenting habit of the yellowfin is demonstrated by the high occurrence in its diet of Crustacea (such as stomatopods and crab larvae) and reef-dwelling fishes of the families Acanthuridae and Balistidae (Reintjes and King, 1953). The more oceanic Bramidae are also common, however. The food of bigeye (King and Ikehara, 1956) is characterized by the high occurrence of such oceanic fishes as the Gempylidae, Bramidae, and Paralepidae. Squid are prominent in the food of all three of the tunas.

Table II

Variation in the volume and composition of the stomach contents of skipjack, yellowfin, and bigeye tuna

| | Average vol. (cc.) per stomach | | | Percentage of occurrence | | | Percentage of total volume | | |
|---|---|---|---|---|---|---|---|---|---|
| | Skipjack | Yellowfin[1/] | Bigeye[2/] | Skipjack | Yellowfin | Bigeye | Skipjack | Yellowfin | Bigeye |
| Crustaceans | .7 | 11.8 | 2.3 | 36.1 | 66.9 | 40.4 | 3.7 | 24.8 | 1.7 |
| Molluscs (total) | 3.9 | 13.3 | 48.2 | 36.4 | - | - | 19.9 | 27.9 | 35.9 |
| Squids | 3.9 | 12.5 | 44.0 | 34.7 | 55.4 | 82.5 | 19.5 | 26.2 | 32.8 |
| Other molluscs | .1 | .8 | 4.1 | 3.4 | - | - | .4 | 1.7 | 3.1 |
| Fish | 14.7 | 22.3 | 83.7 | 67.0 | 70.4 | 84.3 | 74.6 | 46.7 | 62.3 |
| Paralepidae | - | - | 2.6 | .1 | .1 | 10.2 | .1 | - | 2.9 |
| Holocentridae | 5.6 | - | .1 | 4.9 | .1 | .6 | 1.4 | - | - |
| Carangidae | 1.0 | 5.3 | .1 | 4.4 | 2.2 | .6 | 5.2 | 11.1 | - |
| Bramidae | .1 | 1.9 | 29.7 | 2.0 | 13.8 | 15.7 | .7 | 4.1 | 17.2 |
| Mullidae | 1.0 | - | - | 8.2 | - | .6 | 5.1 | - | - |
| Acanthuridae | .1 | .9 | - | 4.8 | 16.8 | - | .5 | 1.9 | - |
| Gempylidae | .6 | .5 | 15.0 | 12.3 | 4.5 | 25.9 | 3.2 | 1.0 | 11.2 |
| Nomeidae | .7 | - | 1.1 | 3.6 | .1 | 13.2 | 3.6 | - | .7 |
| Scombridae | 4.9 | 4.4 | 5.4 | 10.6 | 2.2 | 1.2 | 25.0 | 9.3 | 4.0 |
| Chaetodontidae | .2 | - | - | 6.9 | 1.2 | - | 1.0 | 0.1 | - |
| Balistidae | - | 1.2 | - | .1 | 8.3 | - | - | 2.4 | - |
| Molidae | .7 | .5 | 1.6 | 3.8 | .1 | 1.6 | 3.5 | 1.0 | 1.2 |
| Other foods | .4 | .3 | - | 5.2 | 6.3 | 6.0 | 1.8 | .6 | - |
| All foods | 19.7 | 47.7 | 134.3 | 88.4 | 90.8 | 95.2 | - | - | - |
| Number of stomachs examined | 707 | 1097 | 166 | | | | | | |
| Number of stomachs empty | 82 | 101 | 8 | | | | | | |
| Average fork length (cm.) | 59.7 | 105.1 | 145.6 | | | | | | |
| Average weight (lbs.) | 10.5 | 49.8 | 141.8 | | | | | | |
| Average volume (cc.) food per pound of body weight | 1.9 | 1.0 | .9 | | | | | | |

1/ Data from Reintjes and King, 1953

2/ Data from King and Ikehara, 1956

With respect to volume, fish composed 75 percent of the food of skipjack, squid 20 percent, and Crustacea 4 percent (Fig. 3). The most important fish families, in order of importance, were Scombridae, Carangidae, Mullidae, Nomeidae, and Molidae (Table II). The second and third of these fish families are generally more abundant in coastal waters and near shore habitats; the first and the last two are characteristic of the open ocean. For the yellowfin, Crustacea were large in bulk, and the dominant fish families were Carangidae, Scombridae, and Bramidae; in the bigeye, Crustacea were very low in bulk, and Bramidae, Gempylidae, and Scombridae were important in that order. Matsumoto (1958) has shown that, in plankton hauls made at different depths in the central Pacific, the greatest numbers of tuna larvae were obtained in the upper 50 meters. It is interesting to note that larval and juvenile tunas compose a higher percentage of the food of the more surface-dwelling skipjack and yellowfin than of the deeper-dwelling bigeye.

### 4.1 Variation in food with size of skipjack

There were two principal size groups, with modes at 45 cm. and 72 cm., represented in the 646 skipjack from which stomachs were collected and the fork length recorded (Fig. 4). Secondary modes were evident at 53 cm. and at 78-80 cm. For Hawaiian skipjack, Brock (1954) found modal lengths of 42-45 cm., 68-73 cm., and 79-80 cm., which were interpreted as most likely to represent ages 1, 2 and 3 years respectively. Our 45-cm. mode corresponds, therefore, to Brock's year 1 class, the 72-cm. mode to his year 2 class, and the secondary mode at 78-80 cm. to his year 3 class.

To examine differences in the food related to body size of the skipjack, we split our sample into two size groups: (1) fish less than 60 cm. in fork length (about 10 lbs.), and (2) fish 60 cm. and over. The group of smaller fish (355) averaged 46.4 cm. (4.5 lbs.), whereas the group of larger fish (291) averaged 74.5 cm. (22 lbs.).

The average volume of food per stomach was 15.5 cc. for skipjack less than 60 cm. and 27.4 cc. for those 60 cm. and over. This is in good agreement with Yuen (1959), who noted that volume of stomach contents of skipjack of < 50 cm., 50-60 cm. and > 60 cm. was 9.1 ml., 20.4 ml., and 35.6 ml. respectively. No important difference was noted between the two size groups in respect to the percentage of occurrence or percentage by volume of the major food categories (Fig. 5). However, Yuen (1959) noted an increase in consumption of fish with an increase in the length of skipjack. A detailed survey of the data shows, however, that with an increase in body size the feeding shifted from crab larvae to the more pelagic amphipods and euphausiids and from juvenile carangids and mullids to scombrids and nomeids (Table III), the latter fishes being the more oceanic in their distribution. These variations in composition within the major food categories and the increase in average volume of stomach contents appeared to be the principal differences associated with the increase in body size.

### 4.2 Variation in food with method of capture

Because of the incompleteness of our sampling any differences in the food related to the method of capture of the skipjack are difficult to isolate from differences associated with locality and depth of capture. Skipjack were caught by pole-and-line, surface trolling, purse seine, and longline fishing. In the first three methods the fish were taken on, or near, the surface, and in the latter method they may have been captured well below the surface at depths from 150 to 500 feet. Unfortunately, over 70 percent of our samples from the longline or subsurface-caught fish were from the Line Islands area, whereas over 90 percent of the samples of surface-caught fish were from Hawaiian waters. Also, we should point out that only a small number of stomachs were examined from purse-seine-caught fish, and these came from just two schools. Because of these limitations of the data we shall restrict our conclusions to very generalized remarks.

In respect to variations in the general food categories, crustaceans were small in volume but moderate in number and frequency of occurrence in all three groups of surface-caught skipjack (Fig. 6). Molluscs (principally squids) were low in volume and in number in the pole-and-line and purse-seine-caught fish but were of much greater importance in the troll-caught skipjack. Fish were an important food item in all three groups, but among the troll-caught skipjack they appeared to be replaced to some extent by molluscs.

Among the fish families represented in the food, we find that Scombridae, Carangidae, Mullidae, and Gempylidae were important in the food of the pole-and-line-caught skipjack, as compared with Scombridae and Kuhliidae for the purse-seine-caught fish and Gempylidae and

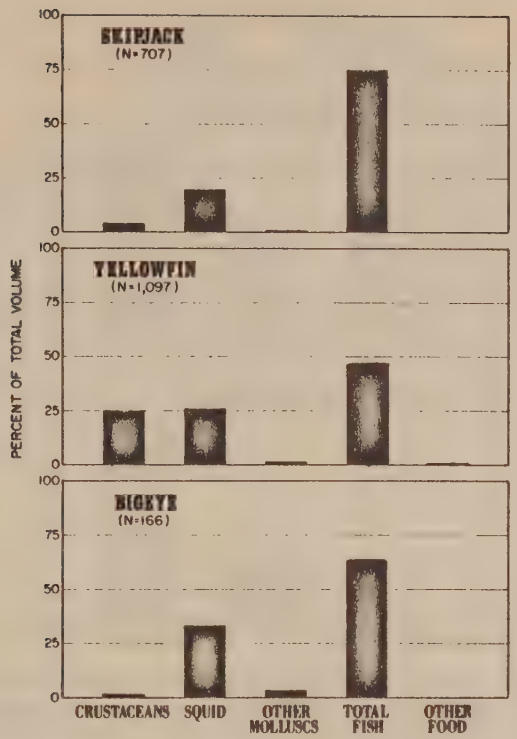


Fig. 3 Percentage of total aggregate volume of the major groups of food organisms for skipjack, yellowfin, and bigeye tuna.

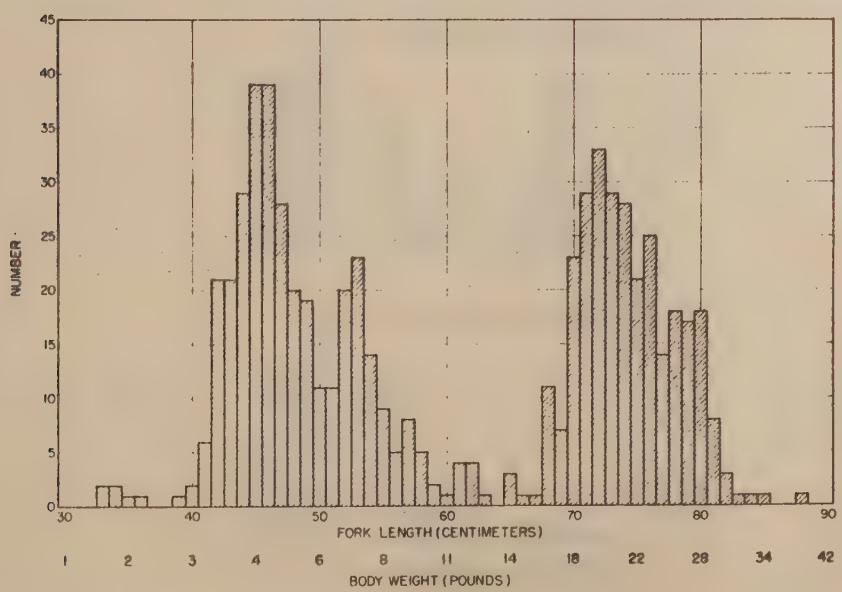


Fig. 4 Length-frequency distribution of 646 skipjack from which stomachs were collected and the fork length recorded.

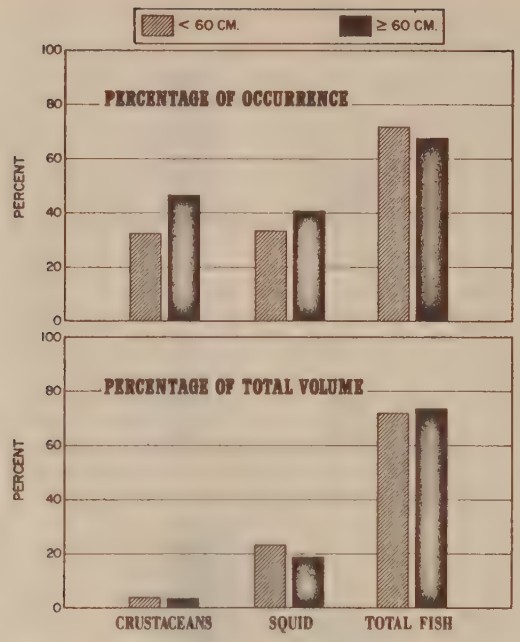


Fig. 5 Percentage of occurrence and percentage of aggregate total volume of the major food elements for skipjack of two size groups, less than 60 cm. and 60 cm. and over in fork length.

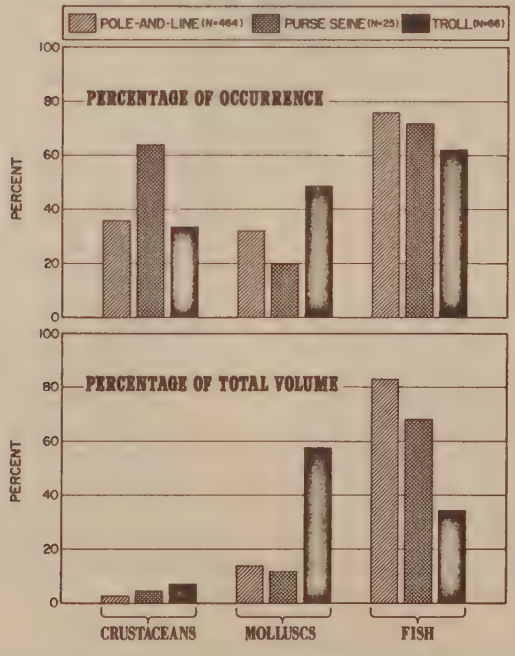


Fig. 6 Variation in the volume and composition of the major categories of the food of surface-caught skipjack as related to method of capture.

Table III

Variation in the food of skipjack
of less than 60 cm. and of
60 cm. and over fork length

| Food organisms | Average volume(cc.) per stomach | | Percentage of occurrence | | Percentage of total volume | |
|---|---|---|---|---|---|---|
| | < 60 cm. Fork length | > 60 cm. Fork length | < 60 cm. Fork length | > 60 cm. Fork length | < 60 cm. Fork length | > 60 cm. Fork length |
| Crustaceans | .6 | 1.0 | 32.7 | 46.7 | 4.0 | 3.7 |
| Molluscs (total) | 3.7 | 5.3 | 34.6 | 41.9 | 23.6 | 19.3 |
| Squids | 3.6 | 5.2 | 33.5 | 40.6 | 23.2 | 18.9 |
| Other molluscs | .1 | - | 1.1 | 6.2 | .4 | .5 |
| Fish (total) | 11.2 | 20.2 | 71.8 | 67.7 | 71.9 | 73.7 |
| Carangidae | 1.3 | .5 | 7.0 | 2.1 | 8.2 | .2 |
| Mullidae | 1.6 | .4 | 13.5 | 3.1 | 10.4 | 1.4 |
| Gempylidae | .8 | .5 | 16.9 | 10.7 | 5.3 | 1.9 |
| Scombridae | 2.1 | 10.2 | 15.2 | 9.3 | 13.4 | 37.3 |
| Nomeidae | .2 | 1.1 | 2.5 | 3.4 | 1.3 | 4.1 |
| Other foods | .1 | .9 | 2.3 | 9.6 | .4 | 3.3 |
| All foods | 15.5 | 27.4 | 85.9 | 87.3 | | |
| Number of stomachs examined | 355 | 291 | | | | |
| Number of stomachs empty | 50 | 37 | | | | |
| Average fork length (cm.) | 46.4 | 74.5 | | | | |
| Average weight (lbs.) | 4.5 | 22.0 | | | | |
| Average volume (cc.) food per pound of body weight | 3.4 | 1.2 | | | | |

Myctophidae for the troll-caught skipjack (Table IV). The most marked difference among these three groups of skipjack, however, was the very low average volume (9.9 cc.) and high percentage of empty stomachs (15 percent) found in the troll-caught fish. This difference is obvious to observers in the field and has also been reported by Welsh (1949). Perhaps surface trolling more than the other fishing methods is selective of fish with near-empty stomachs; or as suggested by Welsh (1949) there may be a higher degree of regurgitation among the troll-caught fish. This difference in volume of stomach contents was not found for troll- and pole-and-line caught yellowfin (Reintjes and King, 1953).

If we compare the volumes and composition of the food of the surface-caught skipjack with those of the subsurface (longline)-caught skipjack, all taken 25 miles or more from land, we find no marked differences in respect to the major categories, although molluscs and crustaceans ranked larger in volume in the subsurface- than in the surface-caught skipjack, whereas fish were just the reverse (Fig. 7).

The fish families most prominent in the stomachs of surface-caught skipjack were Scombridae, Carangidae, Exocoetidae and Molidae, as compared with Gempylidae, Sternoptychidae, and Myctophidae in the subsurface catches (Table V). These occurrences in the food agree generally with what is known of the distribution of these fishes.

The subsurface skipjack (74.2 cm.) averaged larger than the surface-caught fish (64.2 cm.) but contained only about 1/3 as much food in their stomachs (15.66 cc. and 43.7 cc., respectively).

### 4.3 Variation in food with distance from land

In order to examine differences in the food related to the distance of the nearest land from the point of capture of the skipjack, an arbitrary scale of 0-9, 10-24, 25-49, 50-99, 100-199, and 200+ miles was used.

Although the data are few, in Hawaiian waters among the surface-caught skipjack, the average volume of stomach contents increases in an offshore direction out to 50 miles from land and then varies irregularly at further distances offshore (Fig. 8). The samples from 100-199 miles had the lowest average volumes.

The trend described above is largely due to the variation in the volume of fishes, which are the dominant element in the food. Although crustaceans varied irregularly with distance from land, they were most prominent at the 50-99 miles category (Table VI). Molluscs also varied irregularly but were of greatest significance in the 10-24 miles category.

Among the various fish families represented, Scombridae, Gempylidae, and Exocoetidae were important in the offshore category of 100-199 miles. Scombridae were also the most important item in the diet of skipjack taken between 25 and 49 miles offshore, followed by Carangidae, Gempylidae, and Holocentridae. Important fish families in the diet of skipjack taken between shore and 9 miles were Scombridae, Mullidae, and Carangidae. With respect to size, the skipjack sampled in the offshore waters were larger than those of the inshore waters.

### 4.4 Variations related to areas of capture

For an analysis of variations related to area of capture, our data include 506 samples from the Hawaiian area, 92 from the Line Islands area, and 30 from the Phoenix Island area. Results, in terms of frequency of occurrence and volumetric percentages of the major groups of food organisms (Table VII) suggest the following: (1) Skipjack from the Hawaiian area depended on fishes to a greater extent than those from the Phoenix or Line Islands; (2) skipjack from the Phoenix Island area utilized molluscs, crustaceans, and fishes equally as sources of food, and (3) skipjack from the Line Islands area depended on fishes to a lesser degree than those from the other two areas and to a greater extent on squids and crustaceans.

Rather wide differences are found when comparing the diet of skipjack in the central Pacific area with that of skipjack from other areas of the Pacific. Schaefer (1960) noted that in the eastern Pacific the diet includes a much greater volume of Crustacea (62.4 percent) than in the central Pacific (3.7 percent), while the fish and molluscan portions of the diet of eastern Pacific skipjack constituted 4.0 percent and 33.4 percent by volume respectively. The crustacean portion of eastern Pacific skipjack food consisted almost entirely of euphausiids, 57.6 percent and red crabs (Pleuroncodes), 3.8 percent.

Table IV

Variation in the volume and composition of the food of surface-caught skipjack in relation to three methods of capture: pole-and-line, purse seine, and surface trolling

| Food organisms | Average volume (cc.) per stomach | | | Percentage of occurrence | | | Percentage of total volume | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pole-and-line | Purse seine | Surface troll | Pole-and-line | Purse seine | Surface troll | Pole-and-line | Purse seine | Surface troll |
| Crustaceans | .7 | 1.6 | .7 | 36.0 | 64.0 | 33.3 | 2.7 | 4.6 | 7.1 |
| Molluscs (total) | 3.3 | 4.2 | 5.7 | 32.1 | 20.0 | 48.5 | 13.9 | 11.8 | 57.7 |
| Squids | 3.3 | 4.2 | 5.4 | 31.7 | 20.0 | 45.5 | 13.9 | 11.8 | 54.7 |
| Other molluscs | - | - | .3 | 1.3 | - | 7.6 | .1 | - | 3.0 |
| Fish (total) | 19.9 | 24.0 | 3.4 | 75.9 | 72.0 | 62.1 | 83.1 | 68.1 | 34.2 |
| Myctophidae | - | - | .5 | - | - | 3.0 | - | - | 5.3 |
| Holocentridae | .4 | - | - | 7.8 | - | - | 1.8 | - | - |
| Kuhliidae | - | 2.5 | - | - | 4.0 | - | - | 7.2 | - |
| Carangidae | 1.5 | - | - | 6.7 | - | - | 6.4 | - | - |
| Bramidae | .2 | - | .1 | 1.7 | - | 4.5 | .7 | - | .8 |
| Mullidae | 1.4 | - | - | 11.0 | 4.0 | - | 5.7 | - | - |
| Gempylidae | 1.0 | - | .6 | 14.2 | - | 10.6 | 4.1 | - | 5.7 |
| Scombridae | 7.9 | 5.4 | .1 | 16.8 | 20.0 | 3.0 | 32.9 | 15.4 | .9 |
| Nomeidae | .9 | - | - | 3.7 | - | - | 4.0 | - | - |
| Other foods | .1 | 5.4 | .1 | 1.7 | 48.0 | 4.6 | .2 | 15.4 | 1.0 |
| All foods | 23.9 | 35.2 | 9.9 | 87.1 | 96.0 | 84.8 | | | |
| Number of stomachs examined | 464 | 25 | 66 | | | | | | |
| Number of stomachs empty | 60 | 1 | 10 | | | | | | |
| Average fork length (cm.) | 50.5 | 64.2 | 60.9 | | | | | | |
| Average weight (lbs.) | 6.0 | 13.4 | 11.2 | | | | | | |
| Average volume (cc.) food per pound of body weight | 4.0 | 2.6 | 0.9 | | | | | | |

Table V

Variation in the volume and composition
of the food of surface- and subsurface-caught skipjack
taken 25 or more miles from land

| Food organisms | Average volume (cc.) per stomach | | Percentage of occurrence | | Percentage of total volume | |
|---|---|---|---|---|---|---|
| | Surface | Sub-surface (longline) | Surface | Sub-surface (longline) | Surface | Sub-surface (longline) |
| Crustaceans | 1.1 | .9 | 57.0 | 42.3 | 2.5 | 5.8 |
| Molluscs (total) | 3.6 | 9.2 | 78.5 | 72.2 | 8.2 | 59.3 |
| Squids | 3.5 | 9.0 | 78.5 | 67.0 | 8.1 | 57.7 |
| Other molluscs | .1 | .3 | 2.5 | 10.3 | .1 | 1.6 |
| Fish (total) | 39.0 | 5.2 | 80.2 | 51.5 | 89.3 | 33.6 |
| Sternoptychidae | - | 1.1 | - | 4.1 | - | 6.9 |
| Myctophidae | - | .4 | - | 2.1 | - | 2.3 |
| Exocoetidae | 1.2 | - | 7.4 | - | 2.7 | - |
| Carangidae | 1.9 | - | 2.5 | - | 4.3 | - |
| Gempylidae | .5 | .4 | 9.1 | 13.4 | 1.1 | 2.6 |
| Scombridae | 21.5 | .3 | 12.4 | 4.1 | 49.2 | 1.7 |
| Molidae | 1.6 | - | 4.1 | - | 3.7 | - |
| Other foods | - | .2 | 1.7 | 6.2 | .1 | 1.3 |
| All foods | 43.7 | 15.6 | 81.8 | 91.8 | | |
| Number of stomachs examined | 121 | 97 | | | | |
| Number of stomachs empty | 22 | 8 | | | | |
| Average fork length (cm.) | 64.2 | 74.2 | | | | |
| Average weight | 13.4 | 21.7 | | | | |
| Average volume (cc.) food per pound body weight | 3.3 | .7 | | | | |

## Table VI

### Variation in the volume and composition of stomach contents of surface-caught skipjack from Hawaiian waters in relation to distance from land

| | Average volume (cc.) per stomach | | | | | | Percentage of occurrence | | | | | | Percentage of total volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 [1] to 9 | 10 to 24 | 25 to 49 | 50 to 99 | 100 to 199 | 200+ | 0 to 9 | 10 to 24 | 25 to 49 | 50 to 99 | 100 to 199 | 200+ | 0 to 9 | 10 to 24 | 25 to 49 | 50 to 99 | 100 to 199 | 200+ |
| Crustaceans | .5 | .7 | .6 | 1.4 | .2 | 1.2 | 28.4 | 45.3 | 33.1 | 44.2 | 25.8 | 41.4 | 4.3 | 3.3 | 1.4 | 5.3 | 1.6 | 4.5 |
| Molluscs (total) | 2.0 | 5.2 | .8 | 3.6 | .8 | 2.0 | 27.0 | 34.4 | 70.3 | 26.9 | 19.4 | 48.3 | 16.1 | 24.6 | 2.1 | 13.6 | 8.8 | 7.2 |
| Squids | 2.0 | 5.2 | .8 | 3.6 | .7 | 2.0 | 25.0 | 33.6 | 70.3 | 26.9 | 16.1 | 44.8 | 16.0 | 24.5 | 2.1 | 13.6 | 8.1 | 7.2 |
| Other molluscs | - | - | - | - | .1 | - | 2.0 | .8 | - | - | 3.2 | 3.5 | .1 | .2 | - | - | .7 | - |
| Fish (total) | 10.0 | 15.3 | 37.0 | 21.6 | 8.2 | 24.7 | 68.2 | 80.5 | 83.9 | 76.9 | 77.4 | 82.8 | 79.6 | 72.1 | 96.4 | 81.1 | 89.6 | 88.4 |
| Synodontidae | .3 | - | - | - | - | - | 12.2 | 3.1 | .8 | - | - | - | 2.4 | .2 | - | - | - | - |
| Exocoetidae | - | - | .5 | .9 | .6 | 1.1 | .7 | - | 2.5 | 3.8 | 6.5 | 13.8 | .2 | - | 1.4 | 3.6 | 6.2 | 4.0 |
| Holocentridae | .7 | .2 | .6 | - | - | - | 11.5 | 5.5 | 11.9 | 1.9 | - | - | 5.7 | 1.5 | 1.5 | - | - | - |
| Carangidae | 1.1 | 1.2 | 2.8 | 1.7 | - | - | 6.8 | 7.8 | 9.3 | 1.9 | - | - | 8.5 | 7.5 | 7.3 | 6.5 | - | - |
| Mullidae | 1.1 | 3.1 | .5 | .3 | - | - | 12.2 | 21.9 | 5.9 | 5.8 | - | - | 9.0 | 20.4 | 1.4 | 1.2 | - | - |
| Chaetodontidae | .1 | .3 | .2 | 1.0 | - | - | 9.5 | 11.7 | 9.3 | 15.4 | - | - | 1.1 | 2.2 | .4 | 3.8 | - | - |
| Gempylidae | .2 | 1.1 | 1.0 | .9 | 1.3 | .4 | 10.1 | 15.6 | 13.6 | 17.3 | 16.1 | 13.8 | 1.7 | 7.3 | 2.5 | 3.3 | 14.4 | 1.6 |
| Scombridae | 1.7 | 2.4 | 24.9 | 1.7 | 2.0 | - | 15.5 | 24.2 | 18.6 | 5.8 | 12.9 | - | 13.5 | 15.4 | 64.9 | 6.3 | 21.8 | - |
| Molidae | .9 | .6 | .2 | 3.9 | - | 6.0 | 4.7 | 3.1 | 2.5 | 17.3 | - | 17.2 | 6.9 | 3.9 | .1 | 14.8 | - | 21.5 |
| Other foods | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| All foods | 12.5 | 21.2 | 38.4 | 26.6 | 9.2 | 27.9 | 83.1 | 96.9 | 88.1 | 84.6 | 90.3 | 85.7 | | | | | | |
| Number of stomachs examined | 148 | 128 | 118 | 52 | 31 | 29 | | | | | | | | | | | | |
| Number of stomachs empty | 25 | 4 | 14 | 8 | 3 | 5 | | | | | | | | | | | | |
| Average fork length (cm.) | 47.1 | 54.3 | 54.1 | 64.2 | 63.4 | 70.3 | | | | | | | | | | | | |
| Average weight (lbs.) | 4.7 | 7.7 | 7.6 | 13.4 | 12.8 | 18.1 | | | | | | | | | | | | |
| Average volume (cc.) food per pound of body weight | 2.7 | 2.8 | 5.0 | 2.0 | .7 | 1.5 | | | | | | | | | | | | |

1/ Distance from land, in miles.

Table VII

Variation in the volume and composition of the stomach contents of skipjack in relation to area of capture

| Food organisms | Average volume (cc.) per stomach | | | Percentage of occurrence | | | Percentage of total volume | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hawaiian Is. | Line Is. | Phoenix Is. | Hawaiian Is. | Line Is. | Phoenix Is. | Hawaiian Is. | Line Is. | Phoenix Is. |
| Crustaceans | .7 | 1.0 | .5 | 36.0 | 41.3 | 43.3 | 3.0 | 8.4 | 4.0 |
| Molluscs (total) | 2.6 | 8.5 | 3.4 | 29.7 | 58.7 | 60.0 | 11.5 | 70.4 | 26.2 |
| Squids | 2.6 | 8.4 | 3.1 | 29.1 | 57.6 | 46.7 | 11.4 | 69.4 | 24.2 |
| Other molluscs | - | .1 | .3 | 1.2 | 5.4 | 26.7 | .1 | 1.0 | 2.1 |
| Fish (total) | 19.5 | 2.5 | 9.0 | 77.3 | 51.1 | 63.3 | 85.5 | 20.7 | 68.9 |
| Sternoptychidae | - | .7 | 1.0 | .6 | 1.1 | 6.7 | .1 | 5.9 | 8.2 |
| Myctophidae | .2 | .4 | - | .6 | 2.2 | - | .9 | 3.2 | - |
| Carangidae | 1.4 | - | - | 5.9 | - | - | 6.2 | - | - |
| Bramidae | - | - | - | - | 3.3 | - | - | .2 | - |
| Mullidae | 1.4 | - | - | 10.7 | 1.1 | - | 6.0 | .3 | - |
| Gempylidae | .7 | .4 | .8 | 12.3 | 13.0 | 13.3 | 3.2 | 3.8 | 5.9 |
| Scombridae | 7.2 | - | 4.8 | 16.6 | 1.1 | 10.0 | 31.6 | .3 | 36.8 |
| Nomeidae | 1.0 | .1 | - | 4.0 | 5.4 | - | 4.3 | .7 | - |
| Other foods | - | - | .1 | - | 2.2 | 6.7 | - | .4 | .9 |
| All foods | 22.8 | 12.0 | 13.0 | 88.5 | 84.8 | 86.7 | | | |
| Number of stomachs examined | 506 | 92 | 30 | | | | | | |
| Number of stomachs empty | 58 | 14 | 4 | | | | | | |
| Average fork length (cm.) | 56.0 | 69.7 | 66.9 | | | | | | |
| Average weight (lbs.) | 8.5 | 17.7 | 15.4 | | | | | | |
| Average volume (cc.) food per pound of body weight | 2.7 | .7 | .8 | | | | | | |

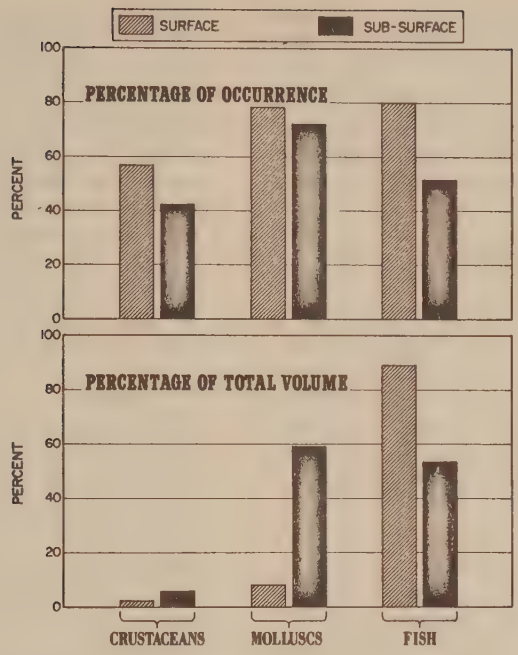


Fig. 7 Variation in the volume and composition of the food of surface-caught (pole-and-line, purse-seine, and troll) and of subsurface-caught (longline) skipjack.

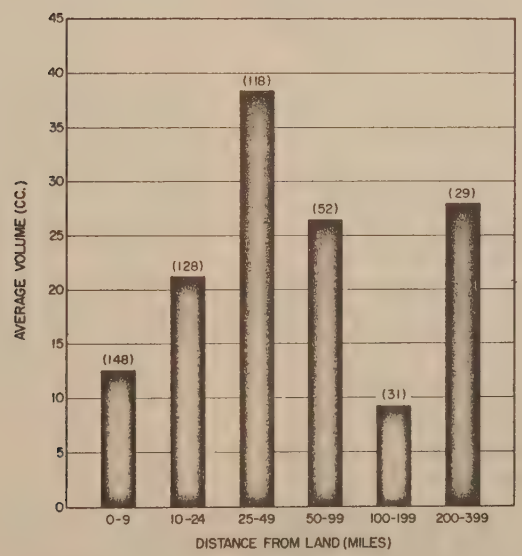


Fig. 8 Variations in the average volume of stomach contents of surface-caught skipjack from Hawaiian waters in relation to distance from land. Figures in parentheses show number of skipjack in sample.

Nakamura (MS) found that Crustacea occurred more frequently in the stomachs of skipjack caught in the waters of French Oceania, 72.3 percent, as compared to skipjack caught in Hawaiian waters, 36.1 percent. The occurrence of molluscs and fish in the stomachs of skipjack from French Oceania was not greatly different from that for Hawaiian waters.

### 4.5 Variations related to time of capture

To examine differences related to time of capture, samples were grouped according to hour of capture, and further summarized into four arbitrary time periods, viz., dawn to 0859, 0900 to 1159, 1200 to 1459, and 1500 to dark. Only samples taken within 9 miles of the shores of the Hawaiian Islands were numerous enough to be used in this analysis.

The results summarized in Table VIII and Fig. 9 suggest that skipjack have a peak feeding period between 0700 and 0900, possibly due to intensified foraging or to a higher availability of forage at this time. Following this peak at 0900 there was a gradual decline in feeding (or availability of food) until 1300. The time between 1300 and 1600 appeared to be a period of little feeding activity, indicated by the lowest volume of stomach contents for the day, followed by a sharp increase in feeding during the late afternoon. Throughout the day fish were the predominant item in the diet, as judged by frequency of occurrence and volume, followed by molluscs, mainly squids, and then by crustaceans.

It is interesting to note that, in this area at least, some of the major food fishes did not appear in stomach contents at all times of day. Table VIII shows that scombrids, carangids, gempylids, acanthurids and molids were not found in stomachs of fish caught before 0900, and in fact, carangids did not appear in any significant quantities until after noon. Mullids, holocentrids, chaetodontids, acanthurids, and molids were not consumed between 1200 and 1500. It seems likely that the sporadic appearance of certain forage organisms in skipjack stomachs reflects not a selective feeding, but rather changes in availability of the different food organisms.

Many of the forage organisms are believed to inhabit deeper water during daylight hours, rising to the surface at night, e.g., squids, myctophids, sternoptychids. Some, such as sternoptychids, apparently move below the vertical range of skipjack during the day and are consumed only during early morning hours. Others, such as squids and myctophids, remain available to skipjack during daylight hours, and, in fact, squid form about one fifth of the food of skipjack caught at all times except the 0900 to 1159 period. This might indicate either (1) a slight preference for squid, sufficient to stimulate an active search, or (2) that the vertical range of the squid and skipjack are very close together and overlap to a certain extent. Since the stomachs of longline-caught skipjack contained more squid than did stomachs of surface-caught skipjack, it is likely that the latter situation pertained.

As no samples were collected during the 12 hours between dusk and dawn, it is not possible to state whether or not skipjack feed at night. Welsh (1949) mentioned the rapid rate of digestion for skipjack, and Nakamura (MS) has found that skipjack confined in a pond pass food (frozen shrimp) through their entire digestive tract in less than 1½ hours. Nakamura further states that pond-held skipjack would not feed at night when the only illumination was a single 150-watt light. This evidence indicates that, if no appreciable feeding takes place after dark, the stomachs of skipjack caught in the early morning should be either (1) empty or (2) contain relatively undigested food. Although the results were generally found to be so, the high incidence of squid in late stages of digestion suggests that feeding occurs at or immediately before dawn.

### 4.6 Seasonal variation

As with the variations by time, only the samples collected within 9 miles of the Hawaiian Islands were numerous enough to permit examination of differences due to seasonal variations in diet. Further, the majority of samples were collected during the summer months so that comparisons for all seasons of the year were not possible. However, certain points of interest emerged when the contents of stomachs sampled in 5 consecutive months during the Hawaiian skipjack season were compared (Table IX). Fig. 10 gives the average food volumes for samples for the months of May to September. There was a noticeable decrease in the average volumes of food for samples collected during mid-summer as compared to samples collected during late spring and early fall and the average volume of food followed very closely that of the fish fraction, which is not surprising, considering the contribution of fish to the diet. The decrease in the molluscan fraction from May to June contributes to the May to June decrease in total

Table VIII

Variation in the volume and composition of the stomach contents of skipjack caught within 9 miles of the Hawaiian Islands in relation to time of capture

| Food organisms | Average volume (cc.) per stomach | | | | Percentage of occurrence | | | | Percentage of total volume | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dawn to 0859 | 0900 to 1159 | 1200 to 1459 | 1500 to Dark | Dawn to 0859 | 0900 to 1159 | 1200 to 1459 | 1500 to Dark | Dawn to 0859 | 0900 to 1159 | 1200 to 1459 | 1500 to Dark |
| Crustaceans | .2 | .9 | .3 | .7 | 28.0 | 31.6 | 14.3 | 34.6 | 2.6 | 4.9 | 3.5 | 5.5 |
| Molluscs (total) | 1.3 | 1.5 | 2.3 | 3.2 | 32.0 | 31.6 | 14.3 | 32.7 | 18.6 | 8.5 | 23.9 | 24.0 |
| Squids | 1.2 | 1.5 | 2.3 | 3.2 | 28.0 | 26.3 | 14.3 | 32.7 | 17.7 | 8.4 | 23.9 | 24.0 |
| Other molluscs | .1 | - | - | - | 4.0 | 5.3 | - | - | .9 | - | - | - |
| Fish (total) | 5.4 | 15.3 | 7.0 | 9.3 | 56.0 | 89.5 | 57.1 | 65.4 | 78.9 | 86.7 | 72.4 | 70.5 |
| Sternoptychidae | .6 | - | - | - | 8.0 | - | - | - | 9.4 | - | - | - |
| Synodontidae | .4 | .5 | - | .2 | 24.0 | 23.7 | - | 7.7 | 6.3 | 3.0 | - | 1.8 |
| Myctophidae | - | 1.7 | - | - | - | 2.6 | - | - | - | 9.6 | - | - |
| Holocentridae | .1 | 1.5 | - | .9 | 4.0 | 21.1 | - | 15.4 | 1.7 | 8.3 | - | 11.1 |
| Carangidae | - | - | 1.0 | 2.3 | - | 2.6 | 3.6 | 9.6 | - | .1 | 10.1 | 17.8 |
| Mullidae | .7 | 3.8 | - | .1 | 8.0 | 36.8 | - | 3.8 | 9.9 | 21.6 | - | .6 |
| Chaetodontidae | .1 | .1 | - | .3 | 8.0 | 7.9 | - | 17.3 | 1.0 | .6 | - | 2.1 |
| Ammodytidae | .2 | .6 | .1 | .7 | 4.0 | 10.5 | 2.6 | 21.2 | 2.3 | 3.5 | .6 | 5.5 |
| Acanthuridae | - | .8 | - | .1 | - | 34.2 | - | 7.7 | - | 4.3 | - | .5 |
| Gempylidae | - | .2 | .2 | .3 | - | 13.2 | 8.6 | 15.4 | - | 1.4 | 1.9 | 2.3 |
| Scombridae | - | .5 | 3.7 | 2.2 | - | 13.2 | 25.7 | 13.5 | - | 2.6 | 38.4 | 16.5 |
| Molidae | - | 3.3 | - | - | - | 15.8 | - | 1.9 | - | 18.9 | - | .1 |
| Other foods | - | - | - | - | - | - | - | - | - | - | - | - |
| All foods | 6.9 | 17.6 | 9.7 | 13.2 | 92.0 | 94.7 | 57.1 | 84.6 | | | | |
| Number of stomachs examined | 25 | 38 | 35 | 52 | | | | | | | | |
| Number of stomachs empty | 2 | 2 | 15 | 8 | | | | | | | | |
| Average fork length (cm.) | 43.5 | 48.5 | 46.5 | 46.3 | | | | | | | | |
| Average weights (lbs.) | 3.7 | 5.2 | 4.6 | 4.5 | | | | | | | | |
| Average volume (cc.) food per pound of body weight | 1.9 | 3.4 | 2.1 | 2.9 | | | | | | | | |

Table IX

Variation in volume and composition of stomach contents of skipjack caught within 9 miles of the Hawaiian Islands in relation to month of capture

| Food organisms | Average volume (cc.) per stomach | | | | | Percentage of occurrence | | | | | Percentage of total volume | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | June | July | Aug. | Sept. | May | June | July | Aug. | Sept. | May | June | July | Aug. | Sept. |
| Crustaceans | 1.0 | .3 | .1 | .5 | 2.4 | 50.0 | 34.1 | 12.8 | 35.2 | 94.1 | 5.3 | 3.1 | 1.0 | 3.4 | 5.4 |
| Molluscs (total) | 6.3 | 2.8 | 3.5 | 4.3 | .1 | 36.5 | 24.4 | 34.6 | 43.7 | 5.9 | 33.2 | 25.0 | 24.9 | 27.9 | .3 |
| Squids | 6.3 | 2.8 | 3.5 | 4.3 | .1 | 33.8 | 24.4 | 34.6 | 43.7 | 5.9 | 33.2 | 25.0 | 24.9 | 27.9 | .3 |
| Other molluscs | - | - | - | - | - | 2.7 | - | - | - | - | - | - | - | - | - |
| Fish (total) | 11.7 | 8.2 | 10.5 | 9.8 | 40.2 | 82.4 | 73.2 | 74.4 | 67.6 | 70.6 | 61.5 | 71.8 | 74.1 | 64.0 | 90.3 |
| Synodontidae | .1 | - | .4 | .1 | - | 4.1 | - | 19.2 | 7.0 | - | .6 | - | 2.7 | 2.9 | - |
| Myctophidae | - | - | - | .9 | - | - | - | - | 1.4 | - | - | - | - | 5.9 | - |
| Holocentridae | - | - | - | 1.8 | .2 | 1.4 | 2.4 | - | 29.6 | 5.9 | - | .2 | - | 11.8 | .5 |
| Carangidae | .9 | - | 3.0 | .4 | - | 5.4 | - | 17.9 | 2.8 | - | 4.9 | - | 21.4 | 2.6 | - |
| Mullidae | 4.6 | 2.5 | 1.7 | .4 | 1.5 | 32.4 | 22.0 | 14.1 | 7.0 | 5.9 | 23.9 | 22.0 | 12.0 | 2.6 | 3.4 |
| Chaetodontidae | .8 | - | - | .2 | - | 21.6 | 2.4 | 6.4 | 9.9 | - | 4.3 | .2 | .3 | 1.3 | - |
| Ammodytidae | - | - | .5 | .4 | - | - | 2.4 | 11.5 | 11.3 | - | - | .4 | 3.4 | 2.9 | - |
| Acanthuridae | - | - | .2 | .3 | - | - | 2.4 | 10.3 | 12.7 | - | - | .2 | 1.1 | 1.7 | - |
| Gempylidae | 2.1 | .3 | .4 | .4 | - | 18.9 | 12.2 | 16.7 | 7.0 | - | 11.2 | 2.5 | 2.8 | 2.9 | - |
| Scombridae | .5 | 2.4 | 2.2 | .2 | 7.9 | 13.5 | 31.7 | 21.8 | 5.6 | 23.5 | 2.6 | 21.5 | 15.7 | 1.0 | 17.8 |
| Nomeidae | - | - | - | 1.5 | - | - | - | - | 8.5 | - | - | - | - | 9.7 | - |
| Molidae | 1.7 | - | - | - | - | 8.1 | - | 1.3 | - | - | 9.0 | - | .1 | - | - |
| Other foods | - | - | - | .7 | 1.8 | - | 2.4 | 1.3 | 7.0 | 35.3 | - | - | - | 4.8 | 4.1 |
| All foods | 19.1 | 11.4 | 14.1 | 15.3 | 44.4 | 97.3 | 78.0 | 84.6 | 91.5 | 100.0 | | | | | |
| Number of stomachs examined | 74 | 41 | 78 | 71 | 17 | | | | | | | | | | |
| Number of stomachs empty | 2 | 9 | 12 | 6 | 0 | | | | | | | | | | |
| Average fork length (cm.) | 55.9 | 55.3 | 49.5 | 50.5 | 61.5 | | | | | | | | | | |
| Average weight (lbs.) | 8.5 | 8.2 | 5.6 | 6.0 | 11.6 | | | | | | | | | | |
| Average volume (cc.) food per pound of body weight | 2.2 | 1.4 | 2.5 | 2.6 | 3.8 | | | | | | | | | | |

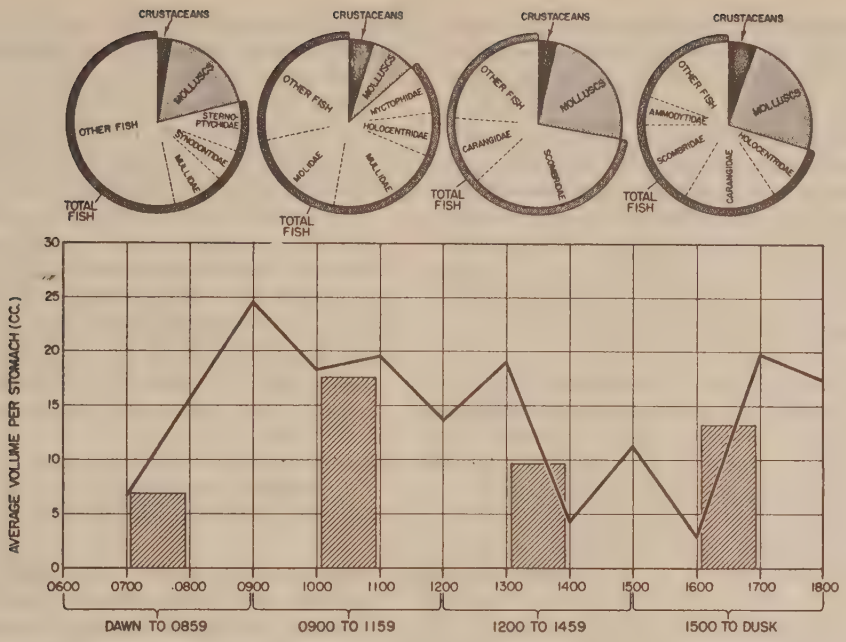


Fig. 9 Average food volume per skipjack stomach in relation to time (hour and time group) of capture, and variation in composition with time group. Sub-divisions of fish show those families which made up more than 5% of the total volume.

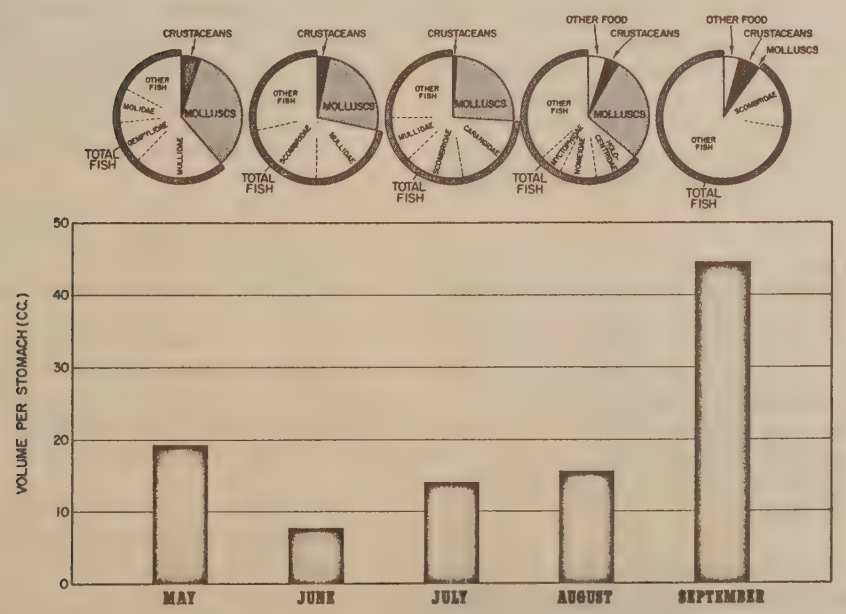


Fig. 10 Food volume per stomach and composition for skipjack caught within 9 miles of land in Hawaiian water related to month of capture.

volume, while the slight July to August increase in total food was due entirely to increases in the molluscan and crustacean fractions. It is difficult to ascertain the cause of this variation as it could have been due to one or a combination of the factors involved in this study. For example, there may be seasonal changes in the abundance of forage organisms, the size of forage organisms consumed may change with season, the general size of food organisms may change due to growth of the organisms, or there may be annual variations in the abundance of forage.

At present the methods of sampling the organisms which comprise the bulk of the food of skipjack are not satisfactory and relatively little is known concerning fluctuations in abundance of the food fauna. Zooplankton abundance (standing crop) has on occasion been used as indirect evidence of changes in abundance of forage organisms.[1/] Although this may be generally so when applied to large areas of the ocean, when applied to smaller regional areas, zooplankton abundance need not necessarily reflect corresponding variations in the abundance of the larger food organisms, i.e., regional areas of equal zooplankton abundance need not have equal abundance of the larger food organisms. In the Hawaiian area, for example, Royce and Otsu (1955) showed an unequal distribution of skipjack schools between the windward and leeward sides of the island chain, while King and Hida (1954) found no significant differences between these same areas with respect to abundance of standing crop of zooplankton at any given time of the year. Because of this it is believed that the unequal distribution of skipjack is caused by some factor other than the abundance of zooplankton.

Analysis of the sizes and compositions of the food organisms shows for the Crustacea a shift from a variety of smaller organisms (average size about .2 cc) through May to August to stomatopods (average size .5 cc) in September; for the Mollusca, stability in composition but a decrease in size in September (4.0 to 1.0 cc); and for the Pisces, a shift from the smaller larval reef forms to the larger, more pelagic forms (2.0 cc to 20.0 cc).

Examination of the average lengths of skipjack from which stomachs were collected shows that with increase in length there is a corresponding increase in food volume. By interpolation of the average lengths of each group, from the results of the greater than 60 cm and less than 60 cm fish analysis, it was found that the variations of the adjusted volumes did not fully account for the larger variations in the average volumes of the monthly samples. Another possible source of the apparent seasonal variation is the unequal sampling by months during different years. Examination of Table I shows that the majority of the September samples were collected during 1954, while samples for May to August were collected during more than one year. If there are annual variations in the abundance of forage organisms, and this is not likely, then this might account for the abrupt pe in September. In this respect it is interesting t note that skipjack catches by the Hawaiian fishery during 1954 were the highest of any year in the 1948-61 period.

Another possibility lies in the rate of feedin during the spawning period. Of interest are the experiences of skipjack fishermen in relation to spawning skipjack. "Spawning schools" encountered during the skipjack season are difficult to fish and are usually abandoned for other schools (Yamashita, 1958). Certain fishes, such as the eel and salmon, stop feeding entirely during spawning migrations, and perhaps the same is true of the skipjack. From this the authors do not feel it unreasonable to presume that the rate of feeding may possibly decrease somewhat before the actual period of spawning. Accordin to the results of the ovarian studies by Brock (1954), a greater number of Hawaiian skipjack may be spawning during the summer months, wi a peak perhaps near the mid-summer months.

## 5 SUMMARY AND CONCLUSIONS

(1) This report is based on the analyses of the stomach contents of 707 skipjack, Katsuwonus pelamis (Linnaeus) taken from the Hawaiian, Line, and Phoenix Islands areas.

(2) The stomach samples were collected during the years 1950-56 by six vessels from a total of 41 cruises and by four different fishing methods: troll (66), purse seine (25), pole-and-line (496), and longline (120).

(3) The food of skipjack consisted of fish (75 percent by volume), squid (20 percent), and crustaceans (4 percent).

(4) General comparisons with the food of yellowfin and bigeye showed, for all three species, utilization of a great variety of organisms. Fish of the family Scombridae were the most important factor for skipjack, while Gempylidae

1/ It is perhaps of interest here that analysis by E. L. Nakamura of the abundance of zooplankton in Hawaiian waters during 1956 reveals a slight decrease in plankton volumes during the mid-summe as compared to late spring and early autumn.

constituted the largest single element among the fish families in terms of food value for yellowfin and bigeye.

(5) Larval and juvenile tuna composed a high percentage of food of skipjack and were also prominent in the food of yellowfin but scarce in that of bigeye.

(6) Relative food values of the more important fish families showed inverse relationships, which somewhat reflects the horizontal and vertical distributions of these fish families, when comparing the foods of bigeye, yellowfin and skipjack.

(7) The skipjack depended to a lesser extent on squid and to a greater extent on fishes as sources of food than did the yellowfin and bigeye.

(8) No significant variation in the major food groups (Crustacea, Mollusca and Pisces) was noted with increase in size except for changes in the composition of the crustacean and fish groups to a more pelagic type.

(9) Average food volumes for troll-caught samples were markedly lower than those for skipjack taken by pole-and-line.

(10) The subsurface fish showed a greater dependency on the squid fauna as a major source of food but with a lower average food volume per stomach than the surface fish, which may indicate that the subsurface level may be poorer in food fauna, causing the larger-sized subsurface fish to search for food throughout a considerable range of depth.

(11) Distance-from-land analysis showed no great variation in the major food groups, with Pisces important throughout; the importance of the different fish families varied with distance from land.

(12) In respect to areas of capture, skipjack from Hawaiian waters showed greater dependency on fishes as source of food than the others; those from near the Phoenix Islands showed an increased dependency on squid, and those from the Line Islands on Crustacea.

(13) Analysis by time of capture gave no indication of preference for food significant enough to influence the diurnal behavior and migrations of skipjack.

(14) Fluctuations in the rate of feeding (food volume) and variations in the consumption of the major food groups (composition) are probably more closely related to the diurnal behavior and migrations of the food fauna than to those of the skipjack.

(15) The average food volume per stomach of Hawaiian skipjack varied during the mid-summer months and increased abruptly in September, perhaps due to uncontrolled variables present in the sampled groups or to variations in composition of food fauna or the rate of feeding during spawning.

Appendix Table I

| Food organisms | Number of organisms | Stomachs in which occurred | | Aggregate total volume | | |
|---|---|---|---|---|---|---|
| | | Number | Percent | Cubic centimeters | Percent | Average volume per stomach |
| ARTHROPODA | | | | | | |
| Crustacea | 2610 | 255 | 36.1 | 518.2 | 3.7 | .7 |
| Unidentified | 2 | 6 | .9 | 16.6 | - | - |
| Copepoda | - | 1 | .1 | 5.0 | - | - |
| Malacostraca | | | | | | |
| Peracarida | | | | | | |
| Mysidacea | | | | | | |
| Mysiidae | 11 | 1 | .1 | .6 | - | - |
| Isopoda | 7 | 4 | .6 | 6.2 | - | - |
| Amphipoda | | | | | .6 | .1 |
| Unidentified | 366 | 71 | 10.0 | 41.9 | .3 | .1 |
| Hyperiidae | 98 | 10 | 1.4 | 30.0 | .2 | - |
| Phronimidae | | | | | | |
| Phronima sp. | 27 | 15 | 2.1 | 9.1 | .1 | - |
| Phrosinidae | 3 | 1 | .1 | 1.0 | - | - |
| Pronoidae | 2 | 1 | .1 | 1.0 | - | - |
| Oxycephalidae | | | | | | |
| Oxycephalus sp. | 5 | 3 | .4 | .3 | - | - |
| Eucarida | | | | | | |
| Unidentified | 7 | 7 | 1.0 | 3.0 | - | - |
| Euphausiacea | | | | | | |
| Euphausiidae | | | | | 0.6 | .1 |
| Unidentified | 127 | 7 | 1.0 | 18.8 | .1 | - |
| Thysanopoda | | | | | | |
| Unidentified | 1 | 1 | .1 | .1 | - | - |
| Thysanopoda tricuspidata | 530 | 4 | .6 | 67.4 | .5 | .1 |
| Euphausia | 9 | 1 | .1 | 2.0 | - | - |
| Decapoda | | | | | 0.7 | |
| Unidentified | 25 | 12 | 1.7 | 5.1 | - | - |
| Natantia | | | | | | |
| Unidentified | 90 | 1 | .1 | 10.0 | .1 | - |
| Pandalidae | | | | | | |
| Heterocarpus ensifer | 1 | 1 | .1 | .5 | - | - |
| Reptantia | | | | | | |
| Scyllaridae | | | | | | |
| Phyllosoma larvae | 2 | 2 | .3 | 1.1 | - | - |
| Nephropsidae | | | | | | |
| Enoplometra | | | | | | |
| Unidentified | 3 | 3 | .4 | 1.1 | - | - |
| Enoplometra occidentalis | 3 | 1 | .1 | 1.0 | - | - |
| Brachyuran megalops | 595 | 94 | 13.3 | 76.8 | .6 | .1 |
| Hoplocarida | | | | | | |
| Stomatopoda | | | | | 1.5 | .3 |
| Squillidae | | | | | | |
| Unidentified | 346 | 89 | 12.6 | 119.4 | .9 | .2 |

Appendix Table I (con.)

| Food organisms | Number of organisms | Stomachs in which occurred | | Aggregate total volume | | |
|---|---|---|---|---|---|---|
| | | Number | Percent | Cubic centimeters | Percent | Average volume per stomach |
| Squilla sp. | 188 | 14 | 2.0 | 23.6 | .2 | - |
| Pseudosquilla | | | | | | |
| Pseudosquilla ciliata | 5 | 3 | .4 | 2.5 | - | - |
| Pseudosquilla occulata | 1 | 1 | .1 | 1.0 | - | - |
| Lysiosquilla sp. | 85 | 21 | 3.0 | 31.6 | .2 | - |
| Coronida sp. | 54 | 13 | 1.8 | 32.2 | .2 | .1 |
| Gonodactylus sp. | 5 | 3 | .4 | 3.1 | - | - |
| Odontodactylus | | | | | | |
| Unidentified | 1 | 1 | .1 | .6 | - | - |
| Odontodactylus hanseni | 11 | 3 | .4 | 5.5 | - | - |
| MOLLUSCA | | | | | | |
| Gastropoda | | | | | | |
| Unidentified | - | 1 | .1 | .5 | - | - |
| Heteropoda | | | | | | |
| Unidentified | 1 | 1 | .1 | 4.0 | - | - |
| Atlantidae | | | | | | |
| Atlanta sp. | 1 | 1 | .1 | .1 | - | - |
| Pteropoda | | | | | | |
| Unidentified | 9 | 3 | .4 | 2.1 | - | - |
| Carolinidae | | | | | | |
| Carolinia sp. | 23 | 6 | .9 | 4.6 | - | - |
| Cephalopoda | | | | | | |
| Octopoda | | | | | | |
| Unidentified | 27 | 5 | .7 | 22.9 | .2 | - |
| Argonautidae | 19 | 10 | 1.4 | 23.9 | .2 | - |
| Decapoda (squid) | 640 | 245 | 34.7 | 2726.9 | 19.5 | 3.9 |
| Unidentified | 579 | 233 | 33.0 | 2357.7 | 16.9 | 3.3 |
| Loliginidae | | | | | | |
| Unidentified | 11 | 6 | .9 | 118.2 | .9 | .2 |
| Sepioteuthis sp. | 1 | 1 | .1 | 34.8 | .3 | .1 |
| Ommastrephidae | | | | | | |
| Unidentified | 41 | 5 | .7 | 106.4 | .8 | .2 |
| Ommastrephes hawaiiensis | 3 | 2 | .3 | 89.5 | .6 | .1 |
| Symplectoteuthis sp. | 5 | 2 | .3 | 20.3 | .2 | - |
| CHORDATA | | | | | | |
| Tunicata | | | | | | |
| Unidentified | 1 | 1 | .1 | 1.0 | - | - |
| Salpidae | 1 | 1 | .1 | 1.0 | - | - |
| Vertebrata (Pisces) | 2827 | 474 | 67.0 | 10,422.2 | 74.6 | 14.7 |
| Unidentified | 631 | 217 | 30.7 | 2472.8 | 17.7 | 3.5 |
| Albulidae | 5 | 4 | .6 | 39.4 | .3 | .1 |
| Clupeidae | | | | | | |
| Unidentified | 12 | 6 | .9 | 56.9 | .4 | .1 |
| Etrumeus micropus | 5 | 3 | .4 | 44.2 | .3 | .1 |

Appendix Table I (con.)

| Food organisms | Number of organisms | Stomachs in which occurred | | Aggregate total volume | | |
|---|---|---|---|---|---|---|
| | | Number | Percent | Cubic centi-meters | Percent | Average volume per stomach |
| Sternoptychidae | | | | | | |
| Unidentified | 49 | 4 | .6 | 81.9 | .6 | .1 |
| Sternoptyx diaphana | 45 | 3 | .4 | 39.0 | .3 | .1 |
| Stomiatidae | 2 | 2 | .3 | 37.0 | .3 | .1 |
| Synodontidae | 119 | 24 | 3.4 | 48.7 | .4 | .1 |
| Paralepidae | 1 | 1 | .1 | 8.1 | .1 | - |
| Alepisauridae | | | | | | |
| Alepisaurus borealis | 3 | 3 | .4 | 12.2 | .1 | - |
| Myctophidae | | | | | | |
| Unidentified | 136 | 5 | .7 | 112.8 | .8 | .2 |
| Diaphus sp. | 12 | 1 | .1 | 64.0 | .5 | .1 |
| Scomberesocidae | | | | | | |
| Cololabis sp. | 4 | 4 | .6 | 93.7 | .7 | .1 |
| Hemirhamphidae | 2 | 2 | .3 | 4.5 | - | - |
| Exocoetidae | | | | | | |
| Unidentified | 13 | 11 | 1.6 | 150.0 | 1.1 | .2 |
| Parexocoetus brachypterus | 1 | 1 | .1 | .5 | - | - |
| Fistulariidae | 1 | 1 | .1 | 1.0 | - | - |
| Syngnathidae | | | | | | |
| Unidentified | 7 | 7 | 1.0 | 3.4 | - | - |
| Hippocampus sp. | 3 | 1 | .1 | 1.4 | - | - |
| Holocentridae | | | | | | |
| Unidentified | 91 | 27 | 3.8 | 168.2 | 1.2 | .2 |
| Holocentrus sp. | 11 | 8 | 1.1 | 28.1 | .2 | - |
| Sphyraenidae | 3 | 2 | .3 | 6.0 | - | - |
| Atherinidae | 2 | 1 | .1 | 2.0 | - | - |
| Kuhliidae | 2 | 1 | .1 | 63.0 | .5 | .1 |
| Priacanthidae | | | | | | |
| Priacanthus cruentatus | 1 | 1 | .1 | 5.6 | - | - |
| Scombropidae | 6 | 3 | .4 | 9.0 | .1 | - |
| Carangidae | | | | | | |
| Unidentified | 2 | 2 | .3 | 6.1 | - | - |
| Decapterus | | | | | | |
| Unidentified | 39 | 25 | 3.5 | 565.8 | 4.1 | .8 |
| Decapterus pinnulatus | 4 | 3 | .4 | 137.0 | 1.0 | .2 |
| Scomberoides sanctipetri | 1 | 1 | .1 | 1.0 | - | - |
| Trachurops crumenophthalus | 1 | 1 | .1 | 15.0 | .1 | - |
| Bramidae | | | | | | |
| Unidentified | 27 | 12 | 1.7 | 92.6 | .7 | .1 |
| Collybus drachme | 2 | 2 | .3 | 1.2 | - | - |
| Coryphaenidae | | | | | | |
| Coryphaena hippurus | 2 | 2 | .3 | 19.0 | .1 | - |
| Mullidae | | | | | | |
| Unidentified | 339 | 53 | 7.5 | 604.8 | 4.3 | .9 |
| Mulloidichthys | | | | | | |
| Unidentified | 1 | 1 | .1 | 20.0 | .1 | - |
| Mulloidichthys auriflamma | 43 | 5 | .7 | 89.9 | .6 | - |
| Chaetodontidae | 148 | 49 | 6.9 | 138.6 | 1.0 | .2 |

Appendix Table I (con.)

| Food organisms | Number of organisms | Stomachs in which occurred | | Aggregate total volume | | |
|---|---|---|---|---|---|---|
| | | Number | Percent | Cubic centimeters | Percent | Average volume per stomach |
| Pomacanthidae | 20 | 11 | 1.6 | 10.5 | .1 | - |
| Blenniidae | 2 | 2 | .3 | 3.7 | - | - |
| Brotulidae | 14 | 3 | .4 | 12.7 | .1 | - |
| Ammodytidae | | | | | | |
| Unidentified | 54 | 15 | 2.1 | 52.4 | .4 | .1 |
| Bleekeria sp. | 36 | 4 | .6 | 19.6 | .1 | - |
| Acanthuridae | 80 | 34 | 4.8 | 71.2 | .5 | .1 |
| Gempylidae | | | | | | |
| Unidentified | 56 | 30 | 4.2 | 177.8 | 1.3 | .3 |
| Gempylus serpens | 114 | 60 | 8.5 | 268.8 | 1.9 | .4 |
| Scombridae | | | | | | |
| Unidentified | 35 | 16 | 2.3 | 100.1 | .7 | .1 |
| Scomber sp. | 13 | 3 | .4 | 23.2 | .2 | - |
| Katsuwonus pelamis | 235 | 55 | 7.8 | 3153.1 | 22.6 | 4.5 |
| Euthynnus yaito | 9 | 4 | .6 | 178.6 | 1.3 | .3 |
| Neothunnus macropterus | 10 | 2 | .3 | 31.6 | .2 | - |
| Scomberomoridae | 1 | 1 | .1 | 3.4 | - | - |
| Tetragonuridae | 1 | 1 | .1 | 1.0 | - | - |
| Nomeidae | | | | | | |
| Unidentified | 4 | 2 | .3 | 86.2 | .6 | .1 |
| Cubiceps sp. | 172 | 23 | 3.3 | 419.2 | 3.0 | .6 |
| Scorpaenidae | | | | | | |
| Unidentified | 11 | 5 | .7 | 9.2 | .1 | - |
| Pontinus sp. | 22 | 9 | 1.3 | 14.4 | .1 | - |
| Scorpaena sp. | 3 | 2 | .3 | 5.0 | - | - |
| Setarchus sp. | 1 | 1 | .1 | 1.0 | - | - |
| Balistidae | | | | | | |
| Unidentified | 2 | 2 | .3 | 3.1 | - | - |
| Balistes ringens | 1 | 1 | .1 | 2.0 | - | - |
| Monacanthidae | 8 | 5 | .7 | 8.6 | .1 | - |
| Ostraciidae | | | | | | |
| Unidentified | 1 | 1 | .1 | .1 | - | - |
| Ostracion diaphana | 4 | 2 | .3 | 4.0 | - | - |
| Tetraodontidae | 5 | 5 | .7 | 11.4 | .1 | - |
| Diodontidae | | | | | | |
| Unidentified | 1 | 1 | .1 | 7.0 | .1 | - |
| Diodon holacanthus | 11 | 1 | .1 | 3.0 | - | - |
| Canthigasteridae | 1 | 1 | .1 | .2 | - | - |
| Molidae | | | | | | |
| Unidentified | 8 | 7 | 1.0 | 127.1 | .9 | .2 |
| Ranzania truncata | 116 | 20 | 2.8 | 336.8 | 2.6 | .5 |
| Unidentified remains | - | 37 | 5.2 | 246.6 | 1.8 | .4 |
| Total food | 6159 | 625 | 88.4 | 13974.0 | | 19.7 |

Number of stomachs examined 707

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# Food of the Bloater, *Coregonus hoyi*, in Lake Michigan

LARUE WELLS AND ALFRED M. BEETON
*U. S. Bureau of Commercial Fisheries, Ann Arbor, Michigan*

ABSTRACT

Stomachs were examined from 1,469 Lake Michigan bloaters, *Coregonus* [*Leucichthys*] *hoyi*, greater than 7 inches long which contained identifiable food. An additional 461 ciscoes less than 7 inches long were incorporated into the study; these latter fish were not positively identified, but most of them undoubtedly were bloaters. The specimens were caught in bottom nets except for 49, all less than 6 inches long, taken in midwater trawls.

Lake Michigan bloaters under 7 inches long depend heavily on zooplankton. Those larger than 7 inches feed predominantly on *Pontoporeia affinis* and *Mysis relicta*, although fish of the 7.0- to 7.9-inch size range commonly eat zooplankton, especially in shallower water. Generally, *Mysis* becomes more important, and *Pontoporeia* less so, as the depth increases and as the season progresses from spring to fall. Incidence of *Pontoporeia* increases and that of *Mysis* declines as the fish size increases. Other food items, in decreasing order of importance, are fingernail clams, midges (all stages of development), fish eggs, ostracods, and miscellaneous adult and immature insects other than midges.

## INTRODUCTION

The bloater has long been of great economic importance in Lake Michigan, either indirectly as food for lake trout or, especially in recent years, for human consumption and as pet and mink-mink food. Since the disappearance of lake trout and the great decline in populations of the large chub[1] species (Moffett, 1957), the production of bloaters has exceeded that of any other species in the Lake Michigan commercial fisheries. Unfortunately, actual records of bloater production are not available, since chubs are not separated by species when sold. It seems safe to assume, however, on the basis of catches by the U. S. Bureau of Commercial Fisheries research vessel *Cisco* and occasional examinations of commercial catches, that at least 90 percent, perhaps 95 percent or more, of the Lake Michigan chubs sold today are bloaters. The annual Lake Michigan commercial catch of chubs during the 10 years 1952–61 averaged about 11 million pounds.

Despite the great abundance of the bloater in Lake Michigan and its considerable abundance in the other Great Lakes except Erie, practically nothing has been written of its food habits. Jobes' (1949) report on the age, growth, and distribution of the Lake Michigan bloater, probably the most thorough single paper on the species to date, contained no information on their diet. The most extensive work on this subject was a preliminary study of the food habits of Lake Michigan chubs in general (Bersamin, 1958).[2] The report by no means constitutes a comprehensive description of the food habits of Lake Michigan bloaters. Zooplankton was completely overlooked as food of these fish, although this item is of great importance. Bersamin listed *Pontoporeia affinis* and *Mysis relicta* as the predominant food organisms of bloaters. Also listed but with scanty quantitative records were fingernail clams (Sphaeriidae), various insects, and chub eggs. He further recorded acanthocephalan worms as food of bloaters and other chubs. His classification of Acanthocephala as food is curious, since he also recognized the worms as parasitic. These worms have *Pontoporeia* as the intermediate host and are ingested with the crustacean by various fish species. The fishes, including bloaters, then become the definitive hosts. Acanthocephalans cannot in any way be construed as food of bloaters.

The only other mention of the food of Lake Michigan bloaters was a statement by Hoy

[1] The name "chub" in this report applies to all Lake Michigan species of the subgenus *Leucichthys* except the lake herring, *Coregonus artedii*. The term "cisco" is often applied to the entire group of *Leucichthys* species.

[2] Although this paper carried a notation of approval by the U. S. Fish and Wildlife Service, the final manuscript was not submitted for review.

(1872) that bloaters and blackfin, *Coregonus nigripinnis*, sampled from depths of 50 to 70 fathoms contained the fingernail clam *Pisidium*, *Mysis*, and three species of the genus *Gammarius* [sic] which are all presently included in the single species *Pontoporeia affinis* (Smith, 1874; Bousfield, 1958). Koelz' (1929) examination of 108 bloater stomachs from Lake Huron indicated that those from water less than 30 fathoms deep contained mostly *Pontoporeia*, and those from water deeper than 60 fathoms had eaten principally *Mysis*. Other food items were fingernail clams (listed as common), insect larvae, and chub eggs. Koelz also examined small numbers of stomachs from other Lake Huron chub species, mostly from water deeper than 60 fathoms; all had eaten primarily *Mysis*. Stomachs from 58 Lake Ontario bloaters contained mostly *Pontoporeia* and *Mysis*; a fair quantity of fingernail clams and insects; and small numbers of cladocerans, copepods, ostracods, and fish eggs (Pritchard, 1931). In the Lake Ontario study, lake herring from the open lake, *C. reighardi*, and *C. kiyi* had eaten essentially the same food as the bloater. No other noteworthy inquiry into the food habits of Great Lakes chubs has been published.

## MATERIALS AND METHODS

### *Identification of specimens*

Four coregonid species of the subgenus *Leucichthys* (the chubs *C. alpenae*, *C. zenithicus*, and *C. reighardi* and the lake herring, *C. artedii*) were caught regularly with the bloaters. Identification of the various species is relatively easy for almost all large individuals, becomes increasingly difficult as the size decreases, and has been impossible for most individuals shorter than 7 inches, total length. With rare exceptions, all chubs shorter than 7 inches which have been taken have had the appearance of bloaters. Since it would appear almost certain that additional small specimens of the "non-bloater" species have been caught, we have concluded that the chub species generally are indistinguishable by present identification methods at lengths less than 7 inches. We assumed, however, that few errors would result if all unidentified small chubs were considered to be bloaters for the purpose of this study, since at least 95 percent of large Lake Michigan chubs during the sampling years were bloaters. Stomachs from 461 fish shorter than 7 inches which were originally classified as unidentified chub have accordingly been incorporated into this study (the few that could be identified clearly as other species were, of course, excluded from the sample). All fish greater than 7 inches, total length, which were examined for this study were identified as bloaters; mis identifications surely were few and probably limited to fish shorter than 8 inches.

TABLE 1.—*Years of collection, depth ranges of sampling, and numbers of stomachs containing identifiable food for each Lake Michigan port of which bloater collections were made*

| Port | Years of collection | Depth range (fathoms) | Number of stomachs containing identifiable food |
|---|---|---|---|
| St. Joseph, Mich. | 1960 | 15–50 | 159 |
| Saugatuck, Mich. | 1962 | 23–45 | 93 |
| Grand Haven, Mich. | 1954, 1960 | 10–51 | 918 |
| Ludington, Mich. | 1954 | 30 | 4 |
| Frankfort, Mich. | 1955, 1961 | 10–51 | 209 |
| Charlevoix, Mich. | 1955, 1961 | 9–50 | 68 |
| Manistique, Mich. | 1955, 1961 | 15–50 | 90 |
| Sturgeon Bay, Wis. | 1955, 1961 | 29–50 | 88 |
| Kewaunee, Wis. | 1955 | 15 | 21 |
| Manitowoc, Wis. | 1954 | 25 | 22 |
| Sheboygan, Wis. | 1954 | 57–60 | 26 |
| Port Washington, Wis. | 1954 | 14–59 | 82 |
| Racine, Wis. | 1954, 1960 | 25–50 | 133 |
| Waukegan, Ill. | 1954 | 15 | 17 |

### *Collection and study of stomachs*

Bloaters for stomach-content analysis were collected off 14 ports widely distributed about the lake (Table 1). All collections were made from the U. S. Bureau of Commercial Fisheries research vessel *Cisco*, except for 11 specimens taken April 3, 1962, off Saugatuck, Michigan, by the Bureau's exploratory fishing vessel *Kaho*. Stomachs were examined from 3,141 fish, of which 1,930 contained identifiable food, 1,107 were empty, and 104 had food which was totally unidentifiable (the proportion of bloaters actually caught with empty stomachs was higher than in the above figures, since no samples for food analysis were taken from collections which preliminary field examination demonstrated to be made up entirely, or nearly entirely, of individuals with no food in their stomachs). References to numbers of specimens hereafter hold only for those that contained identifiable food.

Of the 1,930 specimens that did contain d, 1,484 were caught with bottom trawls, 7 with gill nets set on the bottom, and 49 h midwater trawls. Collections were made 1954 (406 stomachs), 1955 (253 stomachs), 0 (955 stomachs), 1961 (223 stomachs), 1962 (93 stomachs). The earliest collions in any year were made April 3, the est December 14. Fish were taken at depths ween 9 and 60 fathoms. In 1954, 1955, d 1962 the entire specimens were preserved; ch collection labeled as to date, depth, and thod of capture; and sent to the Biological boratory in Ann Arbor, Michigan. There fish were measured and the stomachs reved. In 1960 and 1961 the fresh fish were asured, and the stomachs were removed d preserved aboard the vessel.

The stomach contents usually were exmed under a binocular microscope at a power 9×; higher magnification was used ocsionally for identification of plankton. All entifiable food organisms except plankton ere counted. Small numbers (mostly fewer an 100) of plankters also were counted, but rger numbers were estimated. These estiates usually were based on actual counts of estimated fraction of the total. No attempt as made to identify fingernail clams and tracods to species. Plankton was separated to cladocerans and copepods (there were no her types) for enumeration. In addition, hen the plankton was not too thoroughly gested for further identification, notes were ade on species present, and an estimate ade of their relative abundance.

The quantitative data of the present report e given in two forms: percentage frequency occurrence and percentage dry weight. Freuency of occurrence is used so regularly in udies of food habits that no explanation is eeded. The estimation of percentage dry eight, however, differs so greatly from proedures commonly used as to require the folwing explanation and illustration.

*Percentage dry weight.*—No volumetric or ravimetric measurements were made of the ontents of individual stomachs or groups of tomachs. Rather, quantitative estimates of he relative importance of the various food rganisms in a single stomach were made by the application of an appropriate dry-weight index to the count of each food category. The dry-weight indices were based on actual weights of the principal food organisms (*Pontoporeia, Mysis*, and zooplankton) in two samples of each category collected in the spring, summer, and fall (only one spring sample of plankton). *Pontoporeia* was taken by Petersen dredge; *Mysis* and zooplankton were collected by a No. 2 bolting-silk net. The numbers of animals weighed were: *Pontoporeia* (all individuals in a bottom-fauna sample)—91 to 340, average 149; *Mysis* (all individuals in a plankton net sample)—58 to 313, average 100; zooplankton (withdrawn from sample without selection by size)—10,000 to 24,000, average 17,000. All specimens weighed had been preserved in 10 percent formalin and were dried to constant weight at 100° C.

After the weighings were completed, *Pontoporeia* was assigned an index value of 1.0, a figure that held for all three seasons since the mean size of the organisms remained nearly constant. The index values for *Mysis* and zooplankton were then calculated to be: *Mysis*, spring—1.1, summer—1.0, fall—1.6; zooplankton, spring—0.0034, summer—0.0032, fall—0.0046. The sizes of organisms in the stomachs agreed well with sizes in the weighed samples. The size of a particular food organism taken did not change noticeably with increase in the length of the bloaters.

No other food organisms were weighed, but on the basis of their relative size (in comparison with *Pontoporeia*) dry-weight indices were estimated as follows: Fingernail clams—0.1; fish eggs—0.33; midges (all stages of development)—0.2; Ephemeroptera nymphs—0.5; ostracods—0.02. No great precision can be claimed for these estimates, but possible error surely was small since none of the organisms contributed importantly to the food of the bloater.

The use of the dry-weight indices is illustrated by the hypothetical example of Table 2 in which we assume that the sample consists of three bloaters that were homogeneous as to fish length, season, and depth of water at point of capture—the three bases employed for subdivision of the entire collection.

TABLE 2.—*Method of using dry-weight indices to obtain estimates of the relative importance of food organisms in stomachs from a group of fish*

| Food organism (dry-weight index in parentheses) | Specimen | | | Mean |
|---|---|---|---|---|
| | No. 1 | No. 2 | No. 3 | |
| *Pontoporeia* (1.0) | | | | |
| Number in stomach | 20 | 31 | 6 | — |
| Relative dry weight[1] | 20.0 | 31.0 | 6.0 | — |
| Percentage[2] | 56 | 100 | 21 | 59 |
| *Mysis* (1.1) | | | | |
| Number in stomach | 10 | 0 | 20 | — |
| Relative dry weight[1] | 11.0 | 0 | 22.0 | — |
| Percentage[2] | 31 | 0 | 79 | 37 |
| Zooplankton (0.0034) | | | | |
| Number in stomach | 1,000 | 0 | 6 | — |
| Relative dry weight[1] | 3.4 | 0 | 0.0204 | — |
| Percentage[2] | 10 | 0 | <0.5 | 3 |
| Fingernail clams (0.1) | | | | |
| Number in stomach | 10 | 0 | 0 | — |
| Relative dry weight[1] | 1.0 | 0 | 0 | — |
| Percentage[2] | 3 | 0 | 0 | 1 |
| Total relative dry weight | 35.4 | 31.0 | 28.0204 | — |

[1] Number in stomach times weight index.
[2] Percentage of total relative dry weight of all food in stomach.

Bloater No. 1 contained 20 *Pontoporeia*; the product of this number and the dry-weight index of 1.0 was 20.0. Similarly, for *Mysis* the number of animals (10) times the dry-weight index (1.1) was 11.0. Finally, the products were $1{,}000 \times 0.0034 = 3.4$ for zooplankton, and $10 \times 0.1 = 1.0$ for fingernail clams. The sum of the products gave a total "relative" dry weight of 35.4. Percentages contributed by each food item to this total were: *Pontoporeia*, 56; *Mysis*, 31; zooplankton, 10; fingernail clams, 3. The method of calculation was the same for bloaters No. 2 and No. 3.

The percentages of relative dry weight for individual fish are the basic data from which the comparative importance of food items was determined for each group of bloaters. For the group represented in Table 2, for example, it is held that *Pontoporeia* contributed 59 percent (the mean of 56, 100, and 21) of the total food. The corresponding figures for the remaining foods are: *Mysis*, 37; zooplankton, 3; fingernail clams, 1. This procedure gives equal weight to each stomach regardless of the amount of food present.

Only two exceptions had to be made to the values of the dry-weight indices reported above. A few stomachs contained large numbers of extremely small *Pontoporeia*; these small individuals were assigned an estimated dry-weight index of 0.02. The plankton in other stomachs was mostly or entirely the large copepod, *Limnocalanus*; here, again, a estimated index of 0.02 was assigned.

## FOOD OF BLOATERS LESS THAN 6 INCHES LON

### *Fish from midwater*

The extreme scarcity of chubs smaller tha 6 inches long in bottom trawls with smal mesh cod ends indicates that most bloaters o this size live well above the bottom. Attempt to capture these small bloaters from midlevel were generally disappointing, but 49 contain ing food were available from midwater traw samples. All of these fish, which were 1.3 t 5.7 inches long, were taken within 15 fathom of the surface. One was caught over a 2 fathom depth in spring, another over 2 fathoms in summer, 27 over 40 fathoms i summer, and the remaining 20 over 40 fathom in the fall.

Zooplankton made up the entire diet of th bloaters from midwater. Copepods were pres ent in 46 and cladocerans in 45 of the 4 stomachs. The predominant copepods were *Cy clops bicuspidatus* in summer and *Diaptomu* spp. in the fall. Identification of some of th male diaptomids indicated that *D. oregonensi* and *D. sicilis* were the commonest species, bu that *D. minutus* also was present. Other cope pods included *Epischura lacustris* and *Lim nocalanus macrurus* (the latter uncommon) *Daphnia galeata mendotae* was by far th commonest cladoceran, especially in the fal Most individuals of this species were bearin ephippia in the fall. Other cladocerans wer *Daphnia retrocurva* and *Bosmina longirostri* Copepods and cladocerans were of about equa bulk in the stomachs, but cladocerans woul have been relatively less important had mor spring samples been examined. The singl fish caught in the spring contained no cladoc erans, as might be expected in view of th probable absence of cladocerans in the adu form in winter and early spring and thei scarcity until near summer in Lake Michiga (Wells, 1960). Copepods, on the other hand are almost certainly present in the adult form the year round.

### *Fish from the bottom*

In spite of the scarcity of bloaters unde 6 inches long on the bottom in Lake Michigan

1 fish of this size from a great number of vs with bottom trawls were available. Most re from the 9- to 27-fathom depth range; nsequently, no conclusions are possible re- rding differences by depth.

Zooplankton was of outstanding importance the diet of the bloaters under 6 inches ich were caught on the bottom, but not to e exclusion of other items as was true for e fish from midwater. Zooplankters were in .5 percent of the stomachs in the spring, .6 percent in summer, and 88.7 percent in e fall. The corresponding figures for cope- ds alone were 95.5 percent, 84.6 percent, d 84.9 percent; and for cladocerans 4.5 rcent, 79.5 percent, and 75.5 percent. Thus pepods were generally more important than re cladocerans, especially in spring. Fish ntaining nothing but zooplankton amounted 72.7 percent in the spring, 51.3 percent in mmer, and 67.9 percent in the fall. Zoo- ankton made up an average of 74 percent of e dry weight of the food of the individual sh.

The predominant copepods were, as in the idwater collections, *Cyclops bicuspidatus* d *Diaptomus* spp. (*D. sicilis, D. oregonensis,* d *D. ashlandi* were identified). *Epischura custris* was important in some collections— ore so than in the midwater samples. Other pepods were *Limnocalanus macrurus, Senecella calanoides,* and *Mesocyclops edax.* The ost important cladoceran was *Daphnia aleata mendotae,* as in the midwater samples, ut *Bosmina longirostris* was commonest in me collections. Other cladocerans included *olopedium gibberum, Daphnia retrocurva, olyphemus pediculus, Eurycercus lamellatus, eptodora kindti,* and *Chydorus* sp. (the last ur uncommon).

The only other food items which occurred egularly in the bloaters under 6 inches long nd caught on the bottom were *Pontoporeia ffinis, Mysis relicta,* and midge (Tendipedi- ae) larvae and pupae. *Pontoporeia* was ound in 8.8 percent of the stomachs, *Mysis* in .7 percent, and midges in 21.1 percent. The ercentages of the total dry weight of food or the entire sample were 6 percent for *Pontoporeia,* 7 percent for *Mysis,* and 13 per- ent for midges. The shortest bloaters which contained the three foods were: *Pontoporeia,* 4.0 inches; *Mysis,* 4.2 inches; and midges, 3.9 inches.

A 5.5-inch bloater taken off Frankfort, Michigan, in 14 fathoms on August 13, 1961, contained 25 sac fry and a few eyed eggs of an unidentified species of fish. This specimen was the only one examined in the entire study which contained fish.

The only other food items in the stomachs of the small bloaters were ostracods (2 stomachs) and insect parts—Diptera (other than midges) and Coleoptera—each in one stomach.

Despite the limited number of bloaters less than 6 inches long, it is clear that zooplankton is the principal food of these smaller fish. Those caught in midwater, where the vast majority live, contained nothing other than zooplankton, and those caught on the bottom had eaten mostly zooplankton.

### FOOD OF BLOATERS 6.0 TO 6.9 INCHES LONG

Rather large numbers of bloaters in the 6.0- to 6.9-inch size range were caught in trawls and gill nets fished on the bottom in 1954, especially at depths 9 to 27 fathoms, but few were taken in 1955, 1960, and 1961. The reason for this change is not known. Since appreciable numbers of these fish were almost certainly present in Lake Michigan in one or more of the latter 3 years, it seems that practically all must have been in midwater. Unfortunately, only a few bloaters of this size were caught in midwater fishing, and none were available for this study. The following account is based, therefore, on 298 bloaters 6.0 to 6.9 inches long which were caught on the bottom.

Zooplankton was the most important food. Copepods were found in 56.9 percent of the stomachs in the spring, 38.0 percent in summer, and 39.7 percent in the fall. The corresponding figures for cladocerans were 0.0, 18.0, and 29.4 percent. Fish that contained nothing but zooplankton amounted to 52.8 percent of the specimens in spring, 28.0 percent in summer, and 26.2 percent in the fall. Zooplankton averaged 77 and 72 percent of the dry weight among individuals taken in spring and summer at 9 to 27 fathoms, but the

TABLE 3.—*Percentage frequency of occurrence of each organism in the diet of Lake Michigan bloate longer than 6.9 inches, by length of fish, season, and depth of water*

| Length of fish (inches), season, and depth (fathoms) | Number of fish | Percentage occurrence of food items | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Ponto-poreia* | *Mysis* | Cope-pods | Cladoc-erans | Finger-nail clams | Fish eggs | Midges | Other insects | Ostraco |
| 7.0– 7.9 | | | | | | | | | | |
| Spring | | | | | | | | | | |
| 9–27 | 120 | 50.0 | 15.0 | 55.0 | 5.0 | 16.7 | 1.7 | 2.5 | 0.8 | 2.5 |
| 28–42 | 77 | 70.1 | 40.3 | 16.9 | 3.9 | 16.9 | 3.9 | 3.9 | 2.6 | 5.2 |
| 43–60 | 86 | 27.9 | 79.1 | 11.6 | — | 5.8 | 9.3 | — | 3.5 | 3.5 |
| Summer | | | | | | | | | | |
| 9–27 | 34 | 29.4 | 17.6 | 67.6 | 14.7 | 11.8 | 2.9 | — | 5.9 | 2.9 |
| 28–42 | 104 | 48.1 | 55.8 | 23.1 | 6.7 | 15.4 | 1.0 | 1.9 | 2.9 | 8.7 |
| 43–60 | 33 | 12.1 | 87.9 | 9.1 | — | 3.0 | 3.0 | 3.0 | — | — |
| Fall | | | | | | | | | | |
| 9–27 | 43 | 44.2 | 51.1 | 20.9 | 25.5 | 16.3 | — | 9.3 | 9.3 | 9.3 |
| 28–42 | 49 | 61.2 | 59.2 | 22.4 | 20.4 | 30.6 | 12.2 | — | — | 8.2 |
| 43–60 | 32 | 18.8 | 78.1 | 34.4 | 31.3 | 6.3 | 3.1 | — | 3.1 | — |
| 8.0– 9.9 | | | | | | | | | | |
| Spring | | | | | | | | | | |
| 9–27 | 102 | 69.6 | 20.6 | 25.5 | 2.9 | 34.3 | 6.8 | 12.7 | 1.0 | 2.9 |
| 28–42 | 89 | 92.1 | 30.3 | 7.9 | 3.4 | 43.8 | 15.7 | 6.7 | 1.1 | 2.2 |
| 43–60 | 69 | 47.8 | 82.6 | 10.1 | — | 10.1 | 5.8 | 1.4 | 1.4 | 7.2 |
| Summer | | | | | | | | | | |
| 9–27 | 46 | 84.8 | 19.6 | 19.6 | 2.2 | 28.3 | 2.2 | 21.7 | 8.7 | — |
| 28–42 | 75 | 61.3 | 57.3 | 18.7 | 10.7 | 26.7 | — | 1.3 | 2.7 | 5.3 |
| 43–60 | 59 | 23.7 | 93.2 | 5.1 | — | 11.9 | 6.8 | — | — | 3.4 |
| Fall | | | | | | | | | | |
| 9–27 | 27 | 88.9 | 22.2 | 3.7 | — | 51.9 | — | 11.1 | — | — |
| 28–42 | 39 | 53.8 | 59.0 | 28.2 | 15.4 | 43.6 | 5.1 | — | 2.6 | 15.4 |
| 43–60 | 41 | 36.6 | 97.6 | 12.2 | 7.3 | 14.6 | 12.2 | — | — | 17.1 |
| 10.0–11.9 | | | | | | | | | | |
| Spring | | | | | | | | | | |
| 9–27 | 51 | 96.1 | 3.9 | — | — | 62.7 | 2.0 | 9.8 | — | — |
| 28–42 | 45 | 95.6 | 11.1 | — | — | 55.6 | 8.9 | 13.3 | — | 6.7 |
| 43–60 | 32 | 90.6 | 31.3 | — | — | 62.5 | 43.8 | 6.3 | — | 21.9 |
| Summer | | | | | | | | | | |
| 9–27 | 29 | 96.6 | 20.7 | — | — | 44.8 | — | — | 3.4 | 3.4 |
| 28–42 | 32 | 68.8 | 46.9 | 6.3 | — | 40.6 | — | 3.1 | — | 12.5 |
| 43–60 | 32 | 71.9 | 50.0 | 3.1 | — | 40.6 | 9.4 | 9.4 | — | 15.6 |
| Fall | | | | | | | | | | |
| 9–27 | 29 | 96.6 | 24.1 | 6.9 | 3.4 | 75.9 | — | 13.8 | — | 13.8 |
| 28–42 | 16 | 43.8 | 62.5 | — | 18.8 | 56.3 | — | — | — | 6.3 |
| 43–60 | 78 | 57.7 | 84.6 | 7.7 | — | 64.1 | 20.5 | 12.8 | — | 26.9 |

figures were much smaller at the other depths. In the fall the proportion of the diet made up by zooplankton (dry-weight basis) was also greatest (32 percent) at the shallower depth range than at the other two depths (20 percent at 28–42 fathoms, 25 percent at 43–60 fathoms). Thus it appears that zooplankton constitutes a substantial portion of the diet in shallow water, a fact which points to its great importance, since the small bloaters taken on the bottom are most plentiful in the shallower water. The species composition of the zooplankton in the food was much the same in the 6.0- to 6.9-inch bloaters as in the smaller ones, except that the proportion of *Limnocalanus* among the copepods was somewhat higher.

*Pontoporeia* was present in 30.0 percent of the stomachs from fish 6.0 to 6.9 inches long—29.8 percent of those from 9–27 fathoms, 36.4 percent from 28–42 fathoms, and 15.6 percent from 43–60 fathoms. The percentages of dry weight of identifiable food made up by *Pontoporeia* at these depth ranges were 26, 35, and 11. Consumption of *Pontoporeia* di not change markedly with season, but the became more important in the shallowes depth range, and less so in the intermediat one, as the seasons progressed.

*Mysis* was more common than *Pontoporei* in the stomachs of bloaters 6.0 to 6.9 inche long. It was found in 59.1 percent of a stomachs and constituted 36 percent of th dry weight. It was eaten much more in th deeper water than in the shallow and becam generally more important as the season progressed.

No other organisms were frequent in th stomachs of the 6.0- to 6.9-inch bloaters Fingernail clams were in 3.4 percent of th stomachs, midge larvae and pupae in 2.8 per cent, ostracods in 2.3 percent, fragments o adult insects (Coleoptera, Hymenoptera, Tri choptera) in 1.7 percent, and fish eggs in 0. percent. The numbers of these organisms i the individual stomachs were usually small.

On the basis of the 100-percent-zooplankto

TABLE 4.—*Percentage frequency of occurrence of food organisms of Lake Michigan bloaters longer than 5.9 inches according to fish length (seasons and depths combined), season (fish lengths and depths combined), and depth (fish lengths and seasons combined)*

[All percentages in this table are unweighted means of the appropriate percentages of Table 3]

| Item | Number of fish | Percentage occurrence of food items | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Pontoporeia* | *Mysis* | Copepods | Cladocerans | Fingernail clams | Fish eggs | Midges | Other insects | Ostracods |
| ngth (inches) | | | | | | | | | | |
| 7.0– 7.9 | 578 | 40.2 | 53.8 | 29.0 | 11.9 | 13.6 | 4.1 | 2.3 | 3.1 | 4.5 |
| 8.0– 9.9 | 547 | 62.1 | 53.6 | 14.6 | 4.7 | 29.5 | 6.1 | 6.1 | 1.9 | 6.0 |
| 10.0–11.9 | 344 | 79.7 | 37.2 | 2.7 | 2.5 | 55.9 | 9.4 | 7.6 | 0.4 | 11.9 |
| ason | | | | | | | | | | |
| Spring | 671 | 71.1 | 34.9 | 14.1 | 1.7 | 34.3 | 10.9 | 6.3 | 1.2 | 5.8 |
| Summer | 444 | 55.2 | 50.0 | 16.9 | 3.8 | 24.8 | 2.8 | 4.5 | 2.6 | 5.8 |
| Fall | 354 | 55.7 | 59.8 | 15.2 | 13.6 | 40.0 | 5.9 | 5.2 | 1.7 | 10.8 |
| pth (fathoms) | | | | | | | | | | |
| 9–27 | 481 | 72.9 | 21.6 | 22.1 | 6.0 | 38.1 | 1.7 | 9.0 | 3.2 | 3.9 |
| 28–42 | 526 | 66.1 | 46.9 | 13.7 | 8.8 | 36.6 | 5.2 | 3.4 | 1.3 | 7.8 |
| 43–60 | 462 | 43.0 | 76.0 | 10.4 | 4.3 | 24.3 | 12.7 | 3.7 | 0.9 | 10.6 |
| and average | 1,469 | 60.7 | 48.2 | 15.4 | 6.4 | 33.0 | 6.5 | 5.3 | 1.8 | 7.5 |

omach contents of bloaters shorter than 6 ches caught in midwater, it is reasonable to ssume that bloaters in the 6.0- to 6.9-inch ngth range from midwater also depend eavily on zooplankton for food. Since the reat majority of the bloaters of this latter ze usually feed in midwater, zooplankton is o doubt much more important in their diet an the findings from the bottom-caught fish ndicate.

### OOD OF BLOATERS 7 INCHES LONG OR LONGER

All bloaters in this study which were 7 nches and longer were caught on the bottom. Their stomach contents are believed to have given a good indication of the food habits of he larger bloaters in Lake Michigan, since arger fish appear to live mostly near the bottom. Identifiable food was found in 1,469 ish of this size range. The discussion that ollows is based on the data for percentage occurrence of each food item (Tables 3 and 4) and the percentage dry weight (Tables 5 nd 6). All averages are unweighted. Particular attention should be given to the summary Tables 4 and 6 which form the principal basis for the discussion in this section. Although some exceptions did occur (as may be seen in Tables 3 and 5), the trends of the percentages according to length of fish were generally similar in different seasons and at different depths, trends with season were similar with different depths and lengths of fish, and trends with depth of water were similar at various seasons and fish lengths.

#### *Pontoporeia affinis*

*Pontoporeia* is, on the whole, the most important item in the diet of Lake Michigan bloaters more than 7 inches long. Its percentage occurrence and percentage dry weight (grand averages) were 60.7 and 51, respectively (Tables 4 and 6). Some stomachs contained more than 200 of these crustaceans, but the usual number was less than 100. *Pontoporeia* was most commonly eaten in shallower water, but was important at all depths. The figures for percentage occurrence and percentage dry weight for all seasons and lengths averaged were 72.9 and 68 at 9 to 27 fathoms, 66.1 and 55 for 28 to 42 fathoms, and 43.0 and 29 for 43 to 60 fathoms. The findings in deeper water are at variance with those of Bersamin (1958), who stated that few *Pontoporeia* were observed in specimens collected at depths greater than 41 fathoms.

Bloaters depend more on *Pontoporeia* as they grow larger. Percentage occurrence and percentage dry weight for *Pontoporeia*, figures for seasons and depths combined, were 40.2 and 33, respectively, for fish 7.0 to 7.9 inches long, 62.1 and 51 at 8.0–9.9 inches, and 79.7 and 69 at 10.0–11.9 inches. *Pontoporeia* became generally less important in the diet of bloaters taken in water more than 27 fathoms

TABLE 5.—*Percentage of dry weight made up by each organism in the diet of Lake Michigan bloater longer than 6.9 inches, by length of fish, season, and depth of water*

[Percentages were computed by procedure outlined in section on materials and methods]

| Length of fish (inches), season, and depth (fathoms) | Number of fish | Percentage dry weight of food items | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Pontoporeia* | *Mysis* | Zooplankton | Fingernail clams | Fish eggs | Midges | Other insects | Ostracods |
| 7.0– 7.9 | | | | | | | | | |
| Spring | | | | | | | | | |
| 9–27 | 120 | 44 | 8 | 47 | —[1] | —[1] | 1 | —[1] | —[1] |
| 28–42 | 77 | 63 | 23 | 12 | —[1] | —[1] | —[1] | —[1] | 1 |
| 43–60 | 86 | 21 | 68 | 4 | 2 | 5 | — | —[1] | —[1] |
| Summer | | | | | | | | | |
| 9–27 | 34 | 28 | 12 | 57 | —[1] | 3 | — | —[1] | —[1] |
| 28–42 | 104 | 43 | 47 | 9 | 1 | —[1] | —[1] | —[1] | —[1] |
| 43–60 | 33 | 10 | 88 | 2 | —[1] | —[1] | —[1] | — | — |
| Fall | | | | | | | | | |
| 9–27 | 43 | 32 | 44 | 17 | 1 | — | 4 | 2 | —[1] |
| 28–42 | 39 | 45 | 43 | 9 | 2 | —[1] | — | — | —[1] |
| 43–60 | 32 | 8 | 72 | 19 | 1 | —[1] | — | —[1] | — |
| 8.0– 9.9 | | | | | | | | | |
| Spring | | | | | | | | | |
| 9–27 | 102 | 66 | 11 | 17 | 2 | 1 | 3 | — | —[1] |
| 28–42 | 89 | 85 | 10 | 3 | —[1] | 1 | —[1] | 1 | —[1] |
| 43–60 | 69 | 30 | 66 | 2 | 1 | —[1] | —[1] | —[1] | —[1] |
| Summer | | | | | | | | | |
| 9–27 | 46 | 78 | 11 | 6 | —[1] | —[1] | 4 | —[1] | — |
| 28–42 | 75 | 47 | 44 | 7 | 1 | — | 1 | —[1] | —[1] |
| 43–60 | 59 | 17 | 83 | —[1] | —[1] | —[1] | — | — | —[1] |
| Fall | | | | | | | | | |
| 9–27 | 27 | 82 | 17 | —[1] | 1 | — | —[1] | — | — |
| 28–42 | 39 | 41 | 44 | 8 | 4 | 3 | — | —[1] | —[1] |
| 43–60 | 41 | 11 | 86 | 3 | — | —[1] | — | — | —[1] |
| 10.0–11.9 | | | | | | | | | |
| Spring | | | | | | | | | |
| 9–27 | 51 | 96 | 2 | — | —[1] | —[1] | 2 | —[1] | — |
| 28–42 | 45 | 94 | 6 | — | —[1] | —[1] | —[1] | — | —[1] |
| 43–60 | 32 | 82 | 17 | — | —[1] | 1 | —[1] | — | —[1] |
| Summer | | | | | | | | | |
| 9–27 | 29 | 94 | 3 | — | 3 | — | — | —[1] | —[1] |
| 28–42 | 32 | 57 | 41 | —[1] | 1 | — | —[1] | — | —[1] |
| 43–60 | 32 | 56 | 43 | —[1] | 1 | —[1] | —[1] | — | —[1] |
| Fall | | | | | | | | | |
| 9–27 | 29 | 92 | 7 | —[1] | 1 | — | —[1] | — | —[1] |
| 28–42 | 16 | 24 | 60 | —[1] | 15 | — | — | — | —[1] |
| 43–60 | 78 | 30 | 67 | —[1] | 2 | —[1] | —[1] | — | —[1] |

[1] Less than 0.5.

deep as the seasons progressed, but seasonal differences were small at 10 to 27 fathoms. The percentage occurrence and percentage dry weight, fish lengths and depths combined, were 71.1 and 65 in spring, 55.2 and 48 in summer, and 55.7 and 41 in fall. Although *Pontoporeia* was eaten by as large a percentage of the fish in fall as in summer, it was not as important in terms of dry weight.

### *Mysis relicta*

The grand average percentages of occurrence (48.2) and dry weight (37) placed *Mysis relicta* second only to *Pontoporeia affinis*. In some comparisons *Mysis* was more important than *Pontoporeia*. Singly or together these two species made up the bulk of the food in most stomachs. *Mysis* was most commonly eaten in deeper water in fall, and by fish 7.0 to 9.9 inches long. The percentage occurrence and percentage dry weight of *Mysis* according to depth (figures for seasons and lengths averaged) were 21.6 and 13, respectively, for fish from 9 to 27 fathoms; 46.9 and 35 for 28 to 42 fathoms; and 76.0 and 60 for 42 to 60 fathoms. Seasonal percentages (figures for lengths and depths averaged) were 34.9 and 23 for spring; 50.0 and 41 for summer; and 59.8 and 49 for fall. The percentages by length groups (figures for depths and seasons averaged) were 53.8 and 45 for the 7.0- to 7.9-inch interval; 53.6 and 41 for 8.0–9.9 inches; and 37.2 and 27 for 10.0–11.9 inches. Ordinarily individual stomachs contained fewer than 50 *Mysis*, but one had 181.

The extent to which preference and availability have affected the relative proportions of *Pontoporeia* and *Mysis* in the diet at different depths, times of year, and lengths of fish is not known. Evidence exists, however, that the decrease in the ratio of *Pontoporeia* to *Mysis* as depth increases is due to a change

TABLE 6.—*Percentages dry weight made up by each food organism of Lake Michigan bloaters longer than 7.9 inches according to fish length (seasons and depths combined), season (fish lengths and depths combined), and depth (fish lengths and seasons combined)*

[All percentages in this table are unweighted means of the appropriate percentages of Table 5]

| Item | Number of fish | Percentage dry weight of food items | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Pontoporeia* | *Mysis* | Zooplankton | Fingernail clams | Fish eggs | Midges | Other insects | Ostracods |
| Length (inches) | | | | | | | | | |
| 7.0– 7.9 | 578 | 33 | 45 | 19 | 1 | 1 | 1 | —[1] | —[1] |
| 8.0– 9.9 | 547 | 51 | 41 | 5 | 1 | 1 | 1 | —[1] | —[1] |
| 10.0–11.9 | 344 | 69 | 27 | —[1] | 3 | —[1] | —[1] | —[1] | —[1] |
| Season | | | | | | | | | |
| Spring | 671 | 65 | 23 | 9 | 1 | 1 | 1 | —[1] | —[1] |
| Summer | 444 | 48 | 41 | 9 | 1 | —[1] | 1 | —[1] | —[1] |
| Fall | 354 | 41 | 49 | 6 | 3 | —[1] | —[1] | —[1] | —[1] |
| Depth (fathoms) | | | | | | | | | |
| 9–27 | 481 | 68 | 13 | 16 | 1 | —[1] | 2 | —[1] | —[1] |
| 28–42 | 526 | 55 | 35 | 5 | 3 | 1 | —[1] | —[1] | —[1] |
| 43–60 | 462 | 29 | 66 | 3 | 1 | 1 | —[1] | —[1] | —[1] |
| Grand average | 1,469 | 51 | 37 | 8 | 2 | 1 | 1 | —[1] | —[1] |

[1] Less than 0.5.

availability. Merna[3] found that numbers of *Pontoporeia* declined steadily and rather sharply in Lake Michigan as depth increased from 15 to 40 fathoms, and then remained about the same out to 70 fathoms. Subsequent sampling in Lake Michigan from the *Cisco* with Smith–McIntyre and Petersen dredges (Merna's samples were obtained with an orange-peel dredge) also indicated some decrease in numbers of *Pontoporeia* with depth, but not as great or as sharply defined as Merna reported. Eggleton's (1937) data on *Pontoporeia* in Lake Michigan indicated maximum concentrations at depths of 35 to 50 meters (about 19 to 27 fathoms). Eggleton also reported seasonal changes in abundance, but the trends were decidedly different in two successive years. Frequent sampling at a single station in Lake Huron showed no seasonal changes in the abundance of *Pontoporeia* (Peter, 1960). No studies have been published on the abundance of *Mysis* in the Great Lakes in relation to depth and season.

Accurate comparisons of availability of *Pontoporeia* and *Mysis* would, in any event, be extremely difficult because the two species live in different habitats. In the depths at which the bloater samples were taken, *Mysis* is ordinarily found a meter or so above the bottom (Beeton, 1960), whereas *Pontoporeia* is primarily bottom-dwelling. Both crustaceans exhibit some diurnal vertical migration (Wells, 1960; Beeton, 1960), but the migrations of *Mysis* are clearly the greater. The preponderance of *Pontoporeia* in the diet of bloaters more than 10 inches long, which on first consideration would suggest a greater preference for this crustacean than is possessed by smaller bloaters, may then be due simply to a stronger tendency on the part of the larger fish to feed directly on the bottom. This interpretation is supported by the much higher percentage of bloaters longer than 10 inches with mud in their stomachs. Whether the larger fish ate *Pontoporeia* as the most abundant organism they encountered in a quest for food actually on the bottom, or whether they sought out *Pontoporeia* and found the bottom the most rewarding area, is, however, a matter for speculation.

### *Zooplankton*

Zooplankton was the only item of diet besides *Pontoporeia* and *Mysis* which was of noteworthy importance to bloaters of any size longer than 7 inches. Zooplankton became less common in the diet as the length of the fish increased and was uncommon in bloaters over 10.0 inches long. Its percentage dry weight (figures for seasons and depths average) was 19 for fish 7.0 to 7.9 inches long, 5 at 8.0–9.9 inches, and less than 0.5 at 10.0–11.9 inches. Zooplankton was eaten more commonly in the shallower water; the percentage dry weight

[3] Merna, James William. (1960) A benthological investigation of Lake Michigan. M.S. thesis. Mich. State Univ., East Lansing, Mich., 74 pp. (Typewritten)

(data for various lengths and seasons combined) was 16 at 9 to 27 fathoms, 5 at 28 to 42 fathoms, and 3 at 43 to 60 fathoms. The percentage dry weight was greatest in spring and summer (figures for different lengths and water depths averaged); the percentages were 9 in spring, 9 in summer, and 6 in fall.

Copepods were much more plentiful than cladocerans in spring and summer, but the two were of about equal importance in the fall. Copepods were found in 14.1, 16.9, and 15.2 percent of the bloaters in spring, summer, and fall (data for lengths and water depths combined). Corresponding figures for cladocerans were 1.7, 3.8, and 13.6 percent. Species composition of the plankton was similar to that observed in the 6.0- to 6.9-inch fish. *Cyclops bicuspidatus* was the most extensively eaten plankton species.

### *Fingernail clams*

Fingernail clams had been taken by 33.0 percent of the bloaters, all groups combined, but, owing to the small numbers usually present in the individual stomachs, this item averaged only about 2 percent of the dry weight. Stomachs with clams usually contained fewer than 10, but occasionally one contained a considerably higher number (maximum, 105), especially among fish longer than 10 inches.

Fingernail clams became strikingly more frequent in the diet as the bloaters grew larger (percentages of occurrence, figures for seasons and depths averaged, were 13.6 for fish 7.0 to 7.9 inches long, 29.5 at 8.0–9.9 inches, and 55.9 at 10.0–11.9 inches). Clams occurred more frequently in fish collected in spring and fall than in summer, and in the two shallower depths than in 43 to 60 fathoms. Most of the bloaters which contained clams also contained *Pontoporeia*, and often, especially in larger fish, a certain amount of mud.

Fingernail clams from several bloaters collected in November off Grand Haven, Michigan, at depths of 15, 20, 35, 40, and 50 fathoms were identified by Dr. William H. Heard of The University of Michigan. *Pisidium conventus* was found in bloaters from all depths and was the only positively identified species at 35, 40, and 50 fathoms. Other species were *P. lilljeborgi*, *P. nitidum*, and *Sphaerium nitidum*. Identification of clams from other collections might have uncovered other species since many more are known to exist in Lake Michigan (Heard, 1962). Bersamin (1958) listed *Pisidium conventus*, *P. lilljeborgi*, *P. casertanum*, *Sphaerium tenue*, and *S. corneum* from his Lake Michigan chub collection, but gave no further details.

### *Other food*

The remaining food items of Lake Michigan bloaters made up a combined total of only 2 percent of the dry weight. Fish eggs were found in 6.5 percent of the stomachs, midges in 5.3 percent, other insects in 1.8 percent, and ostracods in 7.5 percent. All these items were taken by bloaters in all seasons, at all depths, and by fish of all lengths greater than 7 inches. The percentage-occurrence figures for these uncommon food items are not to be considered exact, since a single unusual collection could have changed the results appreciably.

The figures for fish eggs most probably would have been higher had winter collections been made or more than a single sample taken in early spring. The eggs of the very abundant bloater itself, as well as several other species, are available during late winter and early spring. In the early spring collection (April 3), only 1 of 41 fish taken from 9 to 27 fathoms contained fish eggs, but they were in 13 of 43 stomachs from 27 to 42 fathoms and in 5 of 9 stomachs from 43 to 60 fathoms. The average number of eggs in the latter 5 stomachs was 52, and the maximum was 103.

Midges, in all stages of development, were the only insects eaten with any regularity. Ephemeroptera nymphs (as many as 8 per stomach) were observed occasionally, as were adults, usually fragments, of Coleoptera, Hymenoptera, Trichoptera, and unidentified insects.

Few stomachs contained more than 5 ostracods, but one had 25. Owing to their small numbers in the individual stomachs and their minute size, they constituted a negligible proportion of the dry weight.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Dr. Ralph Hile who critically reviewed the manuscript.

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*Reprinted from*: CRUSTACEANA, Vol. 6 Part 2 1963. — Leiden, E. J. Brill

# OCCURRENCE OF *PRAUNUS FLEXUOSUS* (O. F. MÜLLER) (MYSIDACEA) IN NEW ENGLAND WATERS

BY

ROLAND L. WIGLEY
Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

Seven specimens of *Praunus flexuosus* (O. F. Müller, 1776) were collected with dip net in the harbor at Barnstable, Massachusetts, U.S.A. Barnstable is located n the northern shore of Cape Cod where water temperatures are several degrees ower than those on the southern shore. These specimens were taken April 30, 960, at low tide over a silty-sand bottom at depths of ½ to 1 m below the surface vhere depths to the bottom were 1 to 1½ m. Four specimens are males with engths (anterior carapace margin to the telson posterior end): 15.5, 17.5, 18, and .9 mm. Three specimens are females with lengths: 19.5, 21, and 25 mm.

*Praunus flexuosus* is one of the most abundant mysids inhabiting the shallow vaters of Great Britain, and is common along the coasts of Denmark, Holland, nd northern France. Except for one doubtful report from the Black Sea, this pecies has not been recorded from outside the north European area (Tattersall & Tattersall, 1951). Thus, its occurrence in American waters poses an intriguing question. Has it been an inhabitant of this seacoast for thousands of years, or has t colonized here in recent centuries or decades?

Unfortunately, we have insufficient evidence at this time to determine whether this species became a permanent resident in this area shortly after the northward retreat of the second Wisconsin (Pleistocene) ice sheet — and was overlooked by zoologists during the past century — or whether it was introduced here later, possibly during the past few decades.

All three females in this collection are adults, but only two are ovigerous. The number of eggs per brood produced by European *P. flexuosus* is given as 15 to 40, depending upon age, size, and season (Tattersall & Tattersall, 1951). The largest female (25 mm) in the Barnstable collection contained 44 eggs, it thus ranks slightly higher than its European relatives in this respect.

*Neomysis americana* Smith was the only other mysid taken in the Barnstable collection with *P. flexuosus*.

I wish to thank Dr. Olive S. Tattersall for carefully examining three specimens from this collection, verifying the identification, and for commenting on the size and distribution of this species.

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## ogonophora on the New England ontinental Slope

Abstract. *Two species of Pogo-ophora on the continental slope off uthern New England are reported. wo species were found:* Siboglinum mani *Jägersten and* Siboglinum *sp., undescribed species. The density of th species combined, at 366 m, was per square meter and at 567 m epth, it was 25 per square meter. The ominant macrobenthic organisms with hich they were associated were poly-haete worms and foraminiferans.*

Recent benthic macrofauna collections om the upper continental slope 145 ilometers south of Martha's Vineyard, Massachusetts, contained 11 specimens f the phylum Pogonophora (*1*). Speci-ens of this rarely observed, tubicolous roup of deuterostomes, sometimes re-erred to as beard worms, have not reviously been reported from this re-ion. The only other report of pogo-ophorans from the western North At-antic Ocean is Bayer's account (*2*) escribing fragments—astutely detected mong other organisms—of *Siboglinum* ollected near the edge of the continen-al shelf east of Florida. They were ssociated with the pennatulid *Stylatula* nd polychaetes of the family Chae-opteridae.

Pogonophora were collected by the esearch vessel *Delaware*, 18 June 1962, y means of a Smith-McIntyre grab ampler (0.1 m²). Samples were taken t two localities (stations 54, 39°59′N, 1°00′W; and 55, 39°56′N, 71°00′W) t depths of 366 and 567 m, respectively. The bottom water temperature for sta-ion 54 was 6.6°C and for station 55, t was 5°C. The bottom sediments were rownish olive in color; the texture was ilt-clay at station 54 and silty sand at tation 55. The median grain size was 0.08 mm and 0.16 mm for stations 54 and 55, respectively. A total of four grab hauls were made, two at each station; pogonophorans were present in each haul. Two species were repre-sented: *Siboglinum ekmani* Jägersten and *Siboglinum* sp. The latter species is a new one and is now being studied by E. C. Southward.

Table 1. Catch record (numbers) for Pogonophora collected from the New England continental slope on 18 June 1962. The combined density of *Siboglinum* sp. and *S. ekmani* at station 54 was 30 per square meter and at station 55 it was 25 per square meter.

| Types | Station | |
|---|---|---|
| | 54 | 55 |
| *Siboglinum ekmani* | | |
| Animals | 1 | 3 |
| Tubes | 0 | 7 frags. |
| *Siboglinum* sp. | | |
| Animals | 5 | 2 |
| Embryos | 2 | 0 |
| Tubes | 6 | 0 |

The species *S. ekmani* has been reported from only two localities, both of which are in the eastern North Atlantic area—the Skagerrak (*3*) and southwest of Ireland (*4*). Thus, its occurrence in New England waters reveals a marked westward extension of its known geographic range. Catch records are much too scant to show geographic distributional patterns for individual species in this phylum. The records have so far disclosed little evidence of cosmopolitan or even ocean-wide distribution, which would generally be expected of bathyal species. Consequently, the records for *S. ekmani* from both sides of the Atlantic are an indication that future studies are likely to reveal widespread distribution for other species in this phylum.

Our specimens were collected from depths of 366 m and 567 m, which is somewhat shallower than the reported depth range of European collections of *S. ekmani*. The known depth range for this species in the Skagerrak is 487 to 650 m (*3*) and southwest of Ireland it is 620 to 1280 m (*4*). Since we did not sample deeper than 567 m, their maximum depth of occurrence in the New England region remains unknown. However, we have negative evidence indicating the minimum-depth boundary for both *Siboglinum* sp. and *S. ekmani* in this region is between 180 and 366 m. This evidence is based on the absence of pogonophorans in over 100 samples of benthic fauna from 64 stations uniformly spaced over an area of 12,000 square kilometers in the shallower water (35 to 180 m) adjacent to stations 54 and 55.

Quantitative information on members of this phylum is also sparse, and data given here are limited; however, the results from our samples are reasonably consistent. The catch records, as shown in Table 1, indicate a density of approximately 30 per square meter, both species combined, with *S. ekmani* only about half as abundant as *Siboglinum* sp. Total macrobenthos averaged 1700 specimens per square meter at station 54 and 700 at station 55. Although the numerical density of the pogonophorans was moderately low, these organisms were a significant component at the deeper station. Because of their moderately low density and small size (average diameter about 0.2 mm and length 10 cm), these species formed only a minor portion of the benthic biomass.

The principal organisms with which the New England pogonophorans were associated were generally the same at both localities. At station 54 the dominant organisms were: polychaete worms (Amphinomidae, Chaetopteridae, Maldanidae), foraminiferans (Astrorhizidae and Saccamminidae), and small sipunculoids. At station 55, which was deeper, the dominant organisms were: polychaete worms (Lumbrineridae, Capitellidae, Cirratulidae) and foraminiferans (Astrorhizidae and Saccamminidae).

ROLAND L. WIGLEY
*Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts*

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15 May 1963

# 60.

# A Radioactive Internal Tag for Herring

By

NORMAN J. WILIMOVSKY*

k handling of herring in western North America
ides the use of an external tagging technique
on visual detection. Regardless of high in-
ial visibility, external tags would pass virtually
ected through the present herring processing
s. Previous studies in Alaska and Canada have
the case with which internal tags might be
ed into herring and the relatively low mortality
brought about by internal tagging.

e metallic or magnetic tag has been proven
ally effective in both herring and pilchard
tigations along the West Coast of North America.
ever, investigators using either type of tag
nize that the magnetic and metal detectors miss
rcentage (often large) of tagged fish. Even a
y magnet, located in a powdered-meal line,
sionally is blocked by a sufficient thickness of
so that the magnetic flux is insufficient to
n a whole tag, and tags are lost. More important,
ags that are collected on the magnet at the end
production line have lost much of their potential
lness, since there is no way of determining from
t fish or group of fish they originated. Also the
nt widespread use of electrical machinery in
ction plants greatly increases the electronic
ring problems and difficulty of maintaining
tronic balance circuits in magnetic or metallic
ction equipment.

he cost of developing improved circuitry to
re a greater percentage tag recovery is prohibitively
. In all probability, these more sophisticated
uits would require more skilful technicians and
e consistent maintenance in the field than is
ally feasible. Consequently, development of a
means of detecting an internal tag was sought.
Our objectives were to develop a system with (1)
internal tag that would be easy to apply and to
ect, (2) a tag detection device which would
rate at extremely high levels of sensitivity, (3) a
ection-ejection technique that would isolate only
specimens containing tags. (Equipment previously
ployed for use with internal metal tags would
t up to two dozen fish at a time, and it was often
ssary to dissect specimens to locate one containing
tag.) (4) Finally, the ejection gear was not to interfere with or delay normal processing techniques at reduction plants.

Of the many detecting methods for internal tags considered, several were rejected because their use was impractical under Alaskan field conditions, e.g. because of high cost of operation and maintenance in isolated areas. The only promising technique of detecting a tag in herring when it was screened by a mass of fish, slime, and water appeared to be the employment of a radioactive tag. Radioisotopes have been tried for fish tagging under laboratory conditions, and at least one worker suggested the use of a radioactive fish tag for field use. However, the survey of the problem by Seymour (1957) indicated that for most applications the use of radioisotopes for tagging was not feasible. The single exception was for the type of operation used in taking herring and similar fishes for reduction.

The construction of the equipment described below was carried out by the Fisheries Instrumentation Laboratory, Bureau of Commercial Fisheries, Seattle, Washington. To a great degree the technical competence of Richard Van Haagen and Richard Othberg made the engineering system which we advanced a working practicality. A paper describing the electronics and engineering details has been prepared for publication and the apparatus may be reproduced.

### Description of Equipment

Essentially, the units of the system may be described as follows.

The tags themselves are made of Alnico V magnetic rods $^1/_2$ inch long and $^1/_8$ inch in diameter. Alnico V was chosen because it is the strongest permanent magnet known and because of its cobalt content. The tags are gold-flashed and labelled radioactive. Each bears a serial number and directions for return, should it fall into the hands of a member of the general public. Finally, the tag is coated with transparent polyethylene and sealed to insure inertness in the herring and in sea water. At one of the National Laboratories tags are irradiated to the very low level required for detection by the newly designed sensitive equipment. Gamma emission from Cobalt 60 at a level of 10 microcuries would fall well within safety requirements and would remain within a level to assure detection even if the tag was shielded by a mass of other fish and debris. Preliminary studies have

* Institute of Fisheries, University of British Columbia, ncouver 8, Canada.
This work was performed while the author was with the rine Fisheries Investigations, U. S. Bureau of Commercial heries, Alaska.

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International Commission for Northwest Atlantic Fisheries

known that this level of radiation can be borne by herring without harm.

Tags are packaged in plastic cartridges to facilitate identification and handling efficiency.

Tag injection equipment has been designed and made to insert the tag into the abdominal cavity of the fish. Narcoticized herring (to reduce mortality from handling) are impaled on the injector, and pressure from a foot pedal gently inserts a tag into the peritoneal cavity. At the same time, an antibiotic is sprayed over the tag and over the wound to reduce the possibility of infection*.

Tagged herring are recovered from the commercial catch at reduction plants. The tag detector consists of a radiation detector and associated electronic circuits. The detector unit is relatively unsophisticated, except for the "fail-safe" features of the circuit. The detection unit provides a signal to operate the tagged fish ejector at the proper instant.

The detection and ejection of tagged fish may be accomplished as the fish enter the processing plant. Because the detection equipment is an integral part of the unloading conveyor system, it was designed to eject fish with a minimum of delay to the processing machinery. This in itself is a significant advance, in that plant operators appear to offer less objection to installation of units into the production lines than to the old metal detectors. It is to be recalled that reduction plant operators participate in any tagging program wholly on a voluntary basis. As herring are unloaded, they pass through the plant's weighing machine and thence onto the tagged fish detector and ejector. In essence, the detector and ejector units appear to be part of the conveyor belt. Radiation from any and all tagged fish is picked up by a scintillation detector at the head of the ejector; in a fraction of a second the machine comes to a stop; in a second fraction of a second, the tagged fish and all fish in the immediate neighborhood are ejected from the main conveyor belt, and in a third fraction of a second, the machinery is again in operation at full speed — the total elapsed time being less than three seconds. With this schedule, ejection will not in any way impede plant operations.

The ejected fish are picked up individually by a small conveyor belt, and each is examined for radioactivity. The tagged fish are diverted into a separate receptacle, and all remaining fish are droped back on the main conveyor line at the head of the ejector. Thus, the fish are checked for radioactivity a second time as they pass the radiation counter. One hundred percent efficiency of tag detection is thereby assured. High safety factors and "fail-safe" techniques are built into the machinery. A third detector is located at the terminal end of the ejector and would halt the equipment should any breakdown allow tags to pass the first detection stage.

* Present incomplete experiments suggest that this cautionary feature may not be necessary.

### Safety Provisions

Additional safety measures have been taken to prevent any radioactive tag from reaching the finished meal product.

The magnetic nature of the tag ensures retention even if through some unlikely and nearly impossible chance a tag should pass through the ejector equipment undetected. The tag itself would magnetically attach to the first piece of metallic machinery it contacted. Even if it were ground to a powder, each particle would become a new magnet, and the metallic dust would be retained on plant machinery rather than enter the meal. The metal detector, which is a part of the plant's debris straining equipment, would pick out any minute particles of the tag that might reach the end of the meal line. As a further safeguard and to alleviate possible criticisms from the consumer the meal product is checked with radiation survey meters. To recover tags that may be lost from rotting fish, the holds of herring fishing vessels are examined with survey meters at frequent intervals.

There is relatively little possibility that any person in the general public will come in contact with one of these tagged herring. The meal produced by the reduction operation is used in high protein poultry feeds, and the oil is used in paints, cosmetics, and ore flotation processes. The chances of obtaining a tagged herring in a catch of bait are extremely small. Should this occur, however, the danger from exposure to radiation would be negligible. The prospect of anyone swallowing a tag in a pickled herring is even smaller. If the tag were not discarded in gibbing the fish, the sealed nature of the tag itself insures that, if it were not discovered in chewing, it would pass intact through the digestive system, giving a negligible dose of radiation to the digestive tract. Several tags would have to be *dissolved* in the body fluid before the radiation level in the liver (the organ which accumulates cobalt faster than others) would reach a dangerous point — a most unlikely circumstance.

Further evidence of the inherent safety of the tag and of the low levels of radiation employed are the simplified shipping and storage procedures prescribed by Government regulations. Shipment of tags through U.S. mail in egg crate cartons is permissible.

To monitor any radiation effects on personnel participating in the tagging program, film badges are worn. Personnel using the injection equipment also wear adhesive thumb-type badges.

### Field Operation

widespread use of radioactive materials rently is of concern to the general public. Our osed use of radioactive tags was made known to ublic, processors, wholesalers and health agencies. e use of radioactive materials was to conform to nic Energy Commission specifications, no objec- to our application were registered. In February 960, the U. S. Atomic Energy Commission ted a license for the employment of our technique. stallation of detection and ejection equipment e three operating plants in Southeastern Alaska completed by early summer 1960. Field use of equipment pointed out some shortcomings which relatively easy to rectify. The major problems lved modifying existing plant features to ac- modate our equipment. A limited number of ring was tagged and released during the summer 960, and by the end of the fishing season, some veries were made. Final evaluation of the technique urrently being conducted in Alaska.

### Summary

Use of internal metal tags has been successfully applied to pelagic fish such as herring, but efficient recovery of individual tagged fish has been a major problem in the past. A research and development program designed to perfect a better tag detecting system resulted in the design of a radioactive magnetic tag, tag injection equipment, and associated detection and ejection machinery. The equipment has been designed to detect radioactive tags at high speeds and under heavy radiation-masking conditions, with virtual 100 percent efficiency. The system costs a fraction of that required to make the less efficient magnetic and metallic detectors. Appropriate safety features are an integral part of the system, which has been granted an Atomic Energy Commission license. The technique is currently being used in Southeastern Alaska to study herring (*Clupea harengus pallasii*) populations.

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# FISHERY OCEANOGRAPHY IN THE TROPICAL ATLANTIC

ROBERT C. WILSON

*Bureau of Commercial Fisheries, Biological Laboratory, Washington, D. C.*

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# FISHERY OCEANOGRAPHY IN THE TROPICAL ATLANTIC

ROBERT C. WILSON

*Bureau of Commercial Fisheries, Biological Laboratory, Washington, D. C.*

The announced title of my talk is somewhat misleading. While there has been some oceanographic research in the tropical Atlantic, I do not propose to give a history of it. My intention is, within the time allotted to this presentation, to discuss the background of a research program planned for the tropical Atlantic, together with its reasons for being, and its direction and character.

As many of you know, there is a growing tuna fishery in the tropical Atlantic, pursued by Japanese longline vessels, by French and Spanish live bait vessels, and by a few American tuna clippers. The most significant development is by the Japanese. In Fig. 1 may be seen the growth of the fishery in terms of vessels participating. In Fig. 2 the main Japanese longline fishing grounds during 1960 are depicted. In Fig. 3 is shown the Japanese catch of yellowfin tuna, with the principal species plotted against the fishing effort in boat months. It would ap-

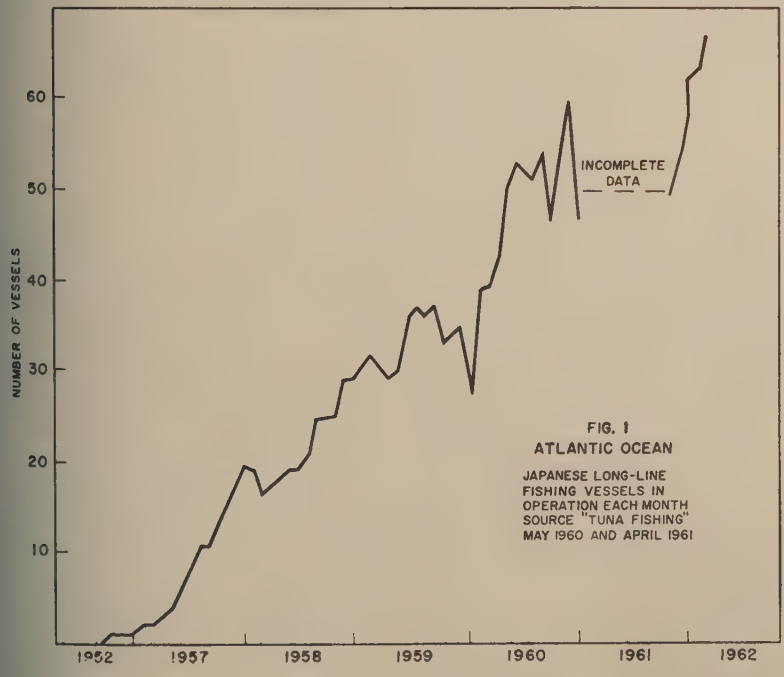



FIG. 1
ATLANTIC OCEAN
JAPANESE LONG-LINE FISHING VESSELS IN OPERATION EACH MONTH
SOURCE "TUNA FISHING" MAY 1960 AND APRIL 1961

FIG. 2
MAIN JAPANESE LONG-LINE FISHING GROUNDS IN 1960

pear that further increases in fishing effort could result in a commensurate increase in catch.

In addition, there are a number of trawlers of many nations taking demersal and midwater fishes; the Russian fleet is the most impressive segment of this fishery. The interest of both African and non-African nations in the fisheries of this region is an expanding one, with announcements of plans and new developments being frequent items in the flow of news concerning fisheries.

There are two important reasons for this interest, first because the eastern tropical Atlantic appears to possess valuable fishery resources, and secondly, because the 80 million people in the humid tropical area about the Gulf of Guinea lack, to a crippling degree, protein in their diet. It is, unfortunately, a characteristic of the humid tropics that while carbohydrate foods can be produced there in abundance, protein foods cannot. There are a variety of reasons for this, among which the prevalence of diseases in domestic animals is an important one in Africa. While the application of modern agricultural science could do much to solve this problem, it would be a time consuming approach because of the research necessary to develop required answers and be

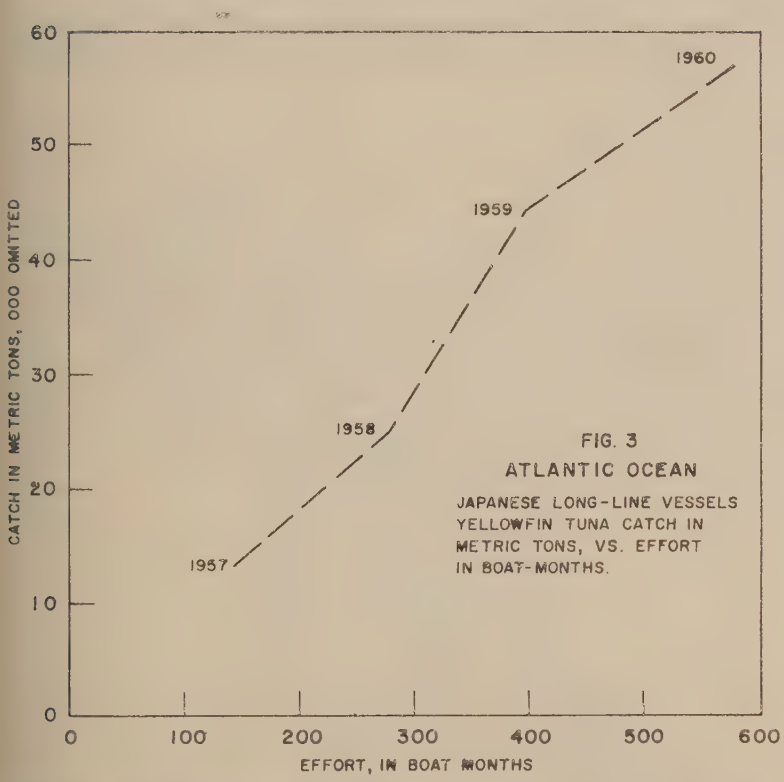


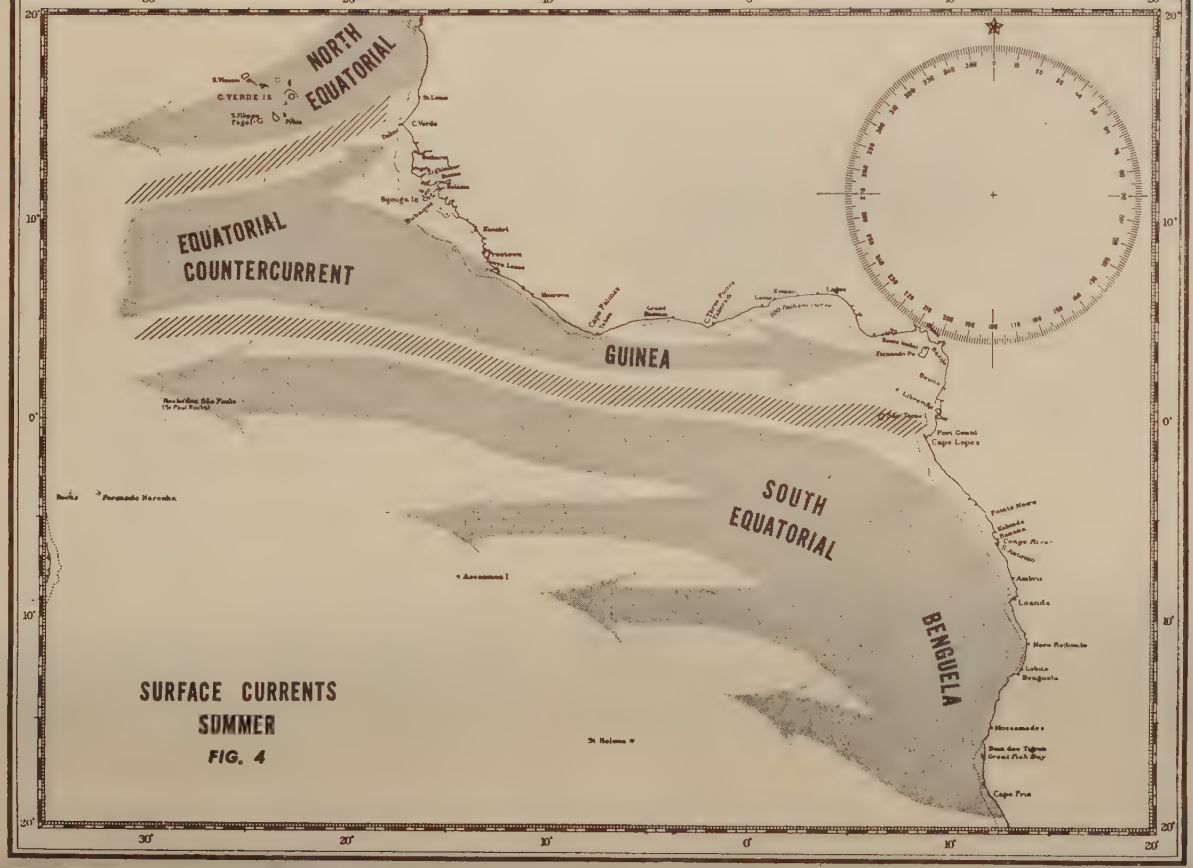

FIG. 3
ATLANTIC OCEAN
JAPANESE LONG-LINE VESSELS YELLOWFIN TUNA CATCH IN METRIC TONS, VS. EFFORT IN BOAT-MONTHS.

cause the application of these answers could require a difficult reeducation of the African farmers.

A direct solution to this problem would be to utilize the available fishery resources. The implementation of such a plan would require the successful solution of a series of problems, beginning with the production of fish and continuing through processing, distribution, and sale.

For both political and humanitarian reasons we are interested in a solution to the problem of protein dietary deficiencies in Africa, as well as other parts of the world. The stability of the new nations of Africa may depend upon it, and the ability of their peoples to effectively progress will be determined by it.

The fishery resources of West Africa are of a number of kinds. Some of these appear to be of susbtantial magnitude but of a character to be of modest unit worth; these resources are obviously of greatest value


NORTH EQUATORIAL
EQUATORIAL COUNTERCURRENT
GUINEA
SOUTH EQUATORIAL
BENGUELA
C. VERDE IS.
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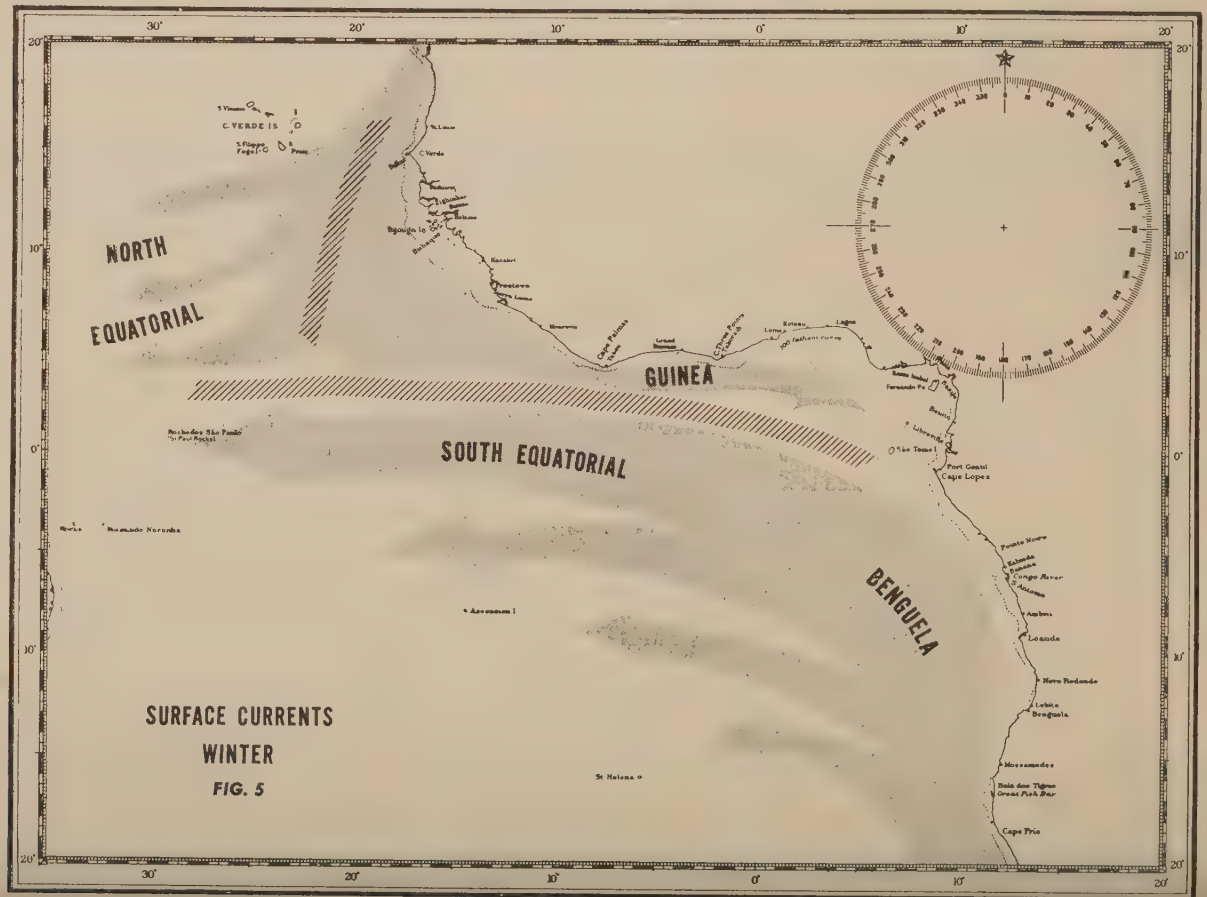
Bathurst
Freetown
Monrovia
Cape Palmas
Grand Bassam
Accra
Lagos
Bonny
Fernando Po
Libreville
Port Gentil
Cape Lopez
Fernando Noronha
Ascension I.
St. Helena
Fomite Noire
Congo River
St. Antonio
Ambriz
Loanda
Novo Redondo
Lobito
Benguela
Mossamedes
Great Fish Bay
Cape Frio
SURFACE CURRENTS
SUMMER
FIG. 4
30°
20°
10°
0°
10°
20°


NORTH
EQUATORIAL
GUINEA
SOUTH EQUATORIAL
BENGUELA
C. VERDE IS.
St. Paul Rocks
Fernando Noronha
Ascension I.
St Helena
Cape Lopez
Cape Frio
SURFACE CURRENTS
WINTER
FIG. 5

SURFACE TEMPERATURES
FEBRUARY
*FIG. 6*

26°
26°
27°
28°
27°
26°
24°
22°
20°
18°
19°
C VERDE IS
SURFACE TEMPERATURES
AUGUST
FIG. 7

as a source of protein in the local diet. Food products based on their use should be most reasonable in cost, other factors being equal. The tropical sardines certainly and possibly some of the demersal fishes are of this kind. Others such as the tunas, being predatory fishes feeding on fish such as the sardines, are likely to be less abundant. In view of the world demand for tunas, the possibility of basing a low cost product for local consumption on their use is poor; however, their exploitation in the waters of the eastern tropical Atlantic would, by reason of the establshment of fishing bases, freezers and canneries, provide considerable income to the people of West Africa.

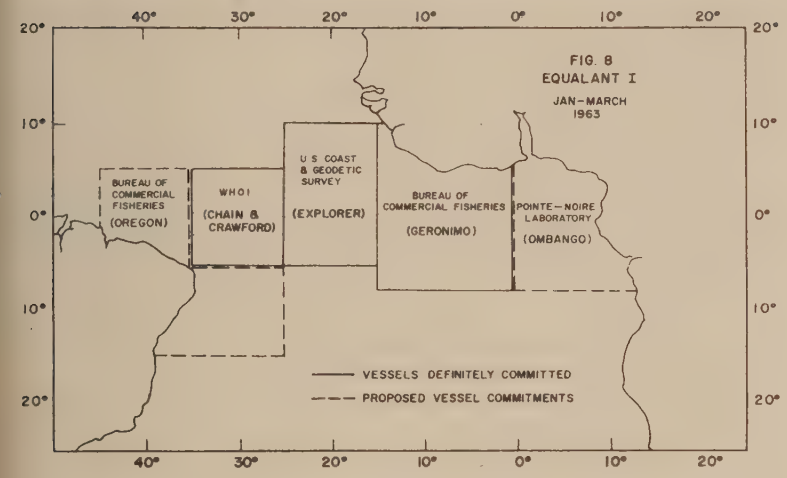
Two research programs, in which we have considerable interest, are now being developed in the fisheries and oceanography of the eastern tropical Atlantic and the waters of the Gulf of Guinea. In addition, there are a number of programs involving both fisheries and oceanographic research now in being which are the individual responsibility of some of the nations of West Africa. These national programs are less in scope than the two mentioned above.

One of these is a survey of the demersal fishes of the African continental shelf. This program is to be conducted by C.C.T.A. which is a regional scientific and technical organization of certain of the African nations south of the Sahara. This organization has applied to the United States for funds to conduct the program and AID (Agency for International Development) has definitely agreed to support it.

The plans involve the use of two trawlers of about 200 to 250 tons to define the limits of trawlable areas between Cape Blanc (Mauritania) and Angola and to determine the nature and abundance of the trawlable fishes. Some oceanographic and bottom data will be taken at each trawling station to relate to the catch. The work will be done in 1963 in two periods of four months duration, the first from January 1 to April 30, and the second from July 1 to October 30. This will permit the survey to cover the two principal climate and fishing seasons in these waters, and the entire area will thus be covered twice.

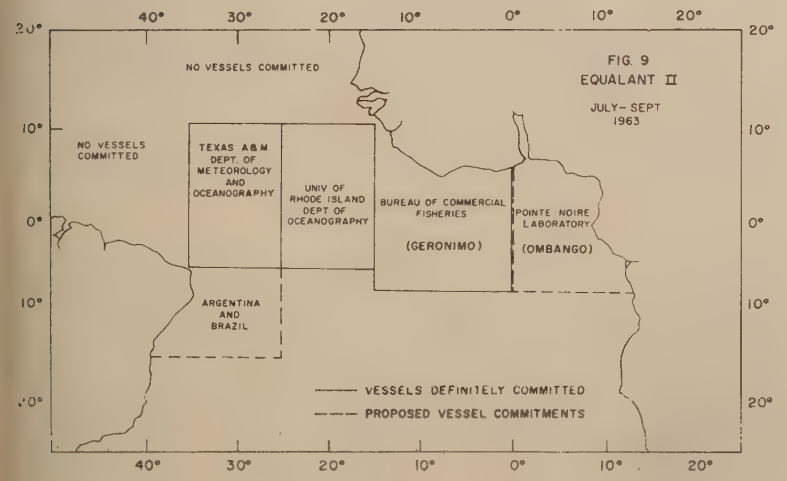
Research vessels of some of the African nations, such as those at Abidjan on the Ivory Coast, Lagos in Nigeria, and Pointe-Noire in French Congo will investigate selected areas during the period of seasonal change—that is during May and June.

The Bureau of Commercial Fisheries is planning a major fisheries and oceanographic research effort in the eastern tropical Atlantic beginning about this same time and coordinated with the program of C.C.T.A. The Bureau's will be concerned with the pelagic fishery resources and the oceanography of the Gulf of Guinea and the eastern tropical Atlantic from about Latitude 20°N to Lat. 15°S and from the African coast to Longitude 30°W. This program was proposed to the




Interagency Committee on oceanography (ICO), and was approved by that group. Currently, the program is under active consideration by ICO for submission to the Intergovernmental Oceanographic Commission as a U. S. sponsored International program.

A suitable vessel will be converted for the program to be ready by January 1963, which will be followed by a second vessel conversion to be ready a year later.



As part of our planning for this program, we have begun a review of what is known concerning the oceanography of the eastern tropical Atlantic.

As may be seen from Fig. 4, the surface currents are complex. During the northern hemisphere summer, the Equatorial Countercurrent is strongly developed, and is the source water for the Guinea current. During the northern hemisphere winter (Fig. 5), on the other hand, the Equatorial Countercurrent is missing, and the North Equatorial Current system is the source water for the Guinea current. The Equatorial Countercurrent water is warm, very saline, and nutrient poor, while the North Equatorial is cooler, more nutrient rich water. Thus we may expect dramatic changes in the distribution of the biota, as well as the weather, in the Gulf of Guinea area. The role of the Equatorial Undercurrent in this area is not clearly understood.

In Fig. 6, showing surface temperatures for February, warm water extends all across the equatorial area, with a pocket of the warmest water in the Gulf of Guinea. During August (Fig. 7), the whole area is affected by cold upwelled water from the south, and by cold water from the north. It is already evident from our review that general knowledge of changes in the biota associated with the physical environmental factors of the area is lacking.

We have, therefore, planned the first year's work (1963) to be oceanography of a general descriptive nature. As a consequence, we invited persons doing oceanographic research, and with a known interest in this area, to a meeting on February 26, 1962, in Washington, D. C., to discuss cooperative research in the tropical Atlantic. Interest was shown by all participants, and plans for synoptic oceanographic surveys of the entire equatorial Atlantic circulation during two periods of calendar 1963 are being developed, called *Equalant I* and *Equalant II*.

It is planned that pelagic fisheries survey work will be carried out during calendar 1964, and 1965, using results from the 1963 work for experimental design of later work.

## DISCUSSION

Discussion Leader Manville: Thank you very much, Mr. Wilson. We have been taken further afield and in a different direction than heretofore this morning. This whole program is a fascinating one, and one quite new to me. Any of you from South Africa or Japan, or for that matter closer to home, are invited to pose your questions to the speaker.

Mr. Clark: I was very interested in seeing what was presented here by Dr. Wilson in terms of big-scale cooperative oceanographic work because we are involved also in the sponsorship of large-scale oceanographic survey programs to extend all along the Atlantic Coast and perhaps into the Gulf of Mexico. The period during which this work will get under way coincides rather well with some of the work proposed in this paper, and I know that there are other large-scale

oceanographic survey programs being launched or proposed. So it appears to me that by 1964 or 1965 there will be a very extensive network of oceanographic survey work being carried out in the Atlantic. Fortunately a lot of it will be directed toward the environment of the sea rather than environment of animals, which is very encouraging to all of us people who are interested in the ecology of the sea and not just the physical properties of the ocean.

CHAIRMAN CROKER: I would like to express, on behalf of all the sponsoring organizations, our thanks for the speaker participation in this really far-flung and widespread program this morning. I am only sorry that our other speaker, Dr. Chapman, was called overseas and could not give his paper, which would, in a sense, tie in the topics that the other speakers touched upon. It is a really big development in the interim to provide food for a hungry world. The oceanographic programs are going forward in all the seas of the world and a tremendous awakening in resources and latent research certainly points for an exciting future in the salt and fresh water world.

17.

# Factors Affecting Number and Quality of Returns from Tagging Cod with Different Tags and using Different Methods of Capture in ICNAF Divisions 4X and 5Y in 1957

By

JOHN P. WISE*

## Introduction

During 1957, cod (*Gadus morhua* L.) captured in ICNAF Divisions 4X and 5Y by both research and commercial line trawlers and by research otter trawler were marked either with Petersen discs on stainless steel wire through the dorsal muscles or with an internally anchored Lea tag. During all except two operations, the types of tags were used alternately, primarily to compare the effectiveness of the two types of tag. Clearcut differences between the tags are apparent in the returns; other factors affecting the returns were also evaluated and are discussed below. Considerable information about movements and migrations was of course obtained from returns, and this will be reported elsewhere.

Table 1 gives a summary of the experiments.

**Table 1**
**Summary of cod tagging experiments, Divisions 4X and 5Y, 1957**

| Place | Month | No. tagged | No. returned | Percent returned |
|---|---|---|---|---|
| Georges Bank ..... | III—IV | 434 | 66 | 15.2 |
| Georges Bank ..... | X | 51 | 2 | 3.9 |
| Browns Bank ..... | III[1]) | 149 | 48 | 32.2 |
| Browns Bank ..... | X | 76 | 11 | 14.5 |
| Cashes Ledge ..... | XI | 50 | 5 | 10.0 |
| Lurcher Shoal ..... | X | 7 | 1 | 14.3 |
| Grand Manan Banks | X—XI | 232 | 7 | 3.0 |
| Fipennies Ledge ... | XI | 7 | 0 | 0 |
| Chatham, Mass. .... | II—III[2]) | 1020 | 253[3]) | 24.8 |
| South Channel .... | X | 177 | 13 | 7.3 |
| Highland Ground .. | X | 237 | 27 | 11.4 |
| | TOTALS | 2440 | 433 | 17.7 |

[1]) Petersen discs used exclusively.
[2]) Lea tags used exclusively.
[3]) Actually 248 fish; 4 caught after tagging, re-released and caught again, and one of these was released and caught yet again.

## Methods and Materials

During line trawl operations, either from research or commercial vessels, fish which appeared not to have been seriously wounded by the hook or other parts of the trawl were gently released from the hook, immediately tagged and measured, and released.

The procedure used while otter trawling was quite different. The trawl net was towed on the bottom for periods varying from perhaps twenty minutes to an hour and a half — the time varied inversely with the abundance of fish. The objective was to secure for tagging a reasonable number of fish which had been in the trawl the shortest time possible.

At the end of the tow, the otter trawl was hauled back, the cod end hoisted aboard, and its contents dumped on deck. As quickly as possible, the fish which were alive and appeared to be in good condition were taken up from the deck by hand and placed in large wooden tanks of running sea water. Dead and distressed fish were culled from the tank, and sometimes when another tank was available the more promising specimens were transferred to a second tank. A measuring board was set up on the edge of the holding tank, and fish were dipnetted as needed for tagging. (While some workers feel it profitable when possible to hold tagged fish in tanks for further culling of weak or dying individuals, this procedure was not followed in any of these operations.)

Measurements were recorded usually to the nearest millimetre in the case of fish less than 900 millimetres in length, to the nearest centimetre when the fish were larger. Because of haste, carelessness or confusion, in some cases the fish were released before being measured. This happened perhaps one percent of the time.

The Lea tag is usually fastened to the dorsal musculature of the fish with a wire bridle, but in these experiments the tags were affixed to a short monel chain which was in turn fastened to a plastic tab inserted through a slit into the coelom.

The Petersen discs used were bright yellow, attached on stainless steel wire through the dorsal musculature. A large hypodermic needle was passed through the muscles just in front of the first dorsal fin and the first interspinous bone. The wire bearing the numbered disc was then pushed through the bore of the needle, the needle withdrawn, another disc placed over the free end of the wire, and the wire cut to length and knotted to hold the two discs firmly in place.

* Former Chief, Cod and Haddock Programs, Woods Hole Biological Laboratory, Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service; now at Food and Agriculture Organization of the United Nations, Grupo Estadual de Pesquisas sôbre a Pesca Marítima, Santos, Estado de São Paulo, Brazil.

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To eliminate as many variables as possible in comparison of the tags, alternate fish were tagged with one type, then with the other. Occasionally this design broke down somewhat under sea conditions; sometimes the tagger on deck ran out of one type of tag before the other, or he started with the wrong type after a period in which no fish were available. However, the principle of alternation was adhered to as far as possible and the records show that in the alternate experiments 632 fish were tagged with discs and 639 with Lea tags. Accurate measurements are available for 625 fish tagged with each sort of tag. The mean length at tagging of fish tagged with discs was 65.3 cm ($\sigma = 20.9$) and with Lea tags 64.1 cm ($\sigma = 20.4$).

The message enclosed in the Lea tags and stamped on one of the pair of Petersen discs states that there is a reward for the return of the tags and gives the laboratory address. While the tags are often returned directly by mail and the reward and information sent out by return mail, agents of the laboratory stationed in various ports have been empowered to pay the reward, a dollar, on the spot and to collect the pertinent information. In the same fashion, agents of the Fisheries Research Board of Canada working under a reciprocal agreement have collected tags and the Board has paid the reward. Since May 1958, agents of the Fish and Wildlife Service have paid an additional dollar when the fish was returned with the tag. These arrangements have undoubtedly fostered getting a good percentage of the recovered tags actually returned to the laboratory — more than if the initiative for sending them in were left entirely to the fishermen. In addition, having the tags and often the fish received by trained technicians has improved the quality of the information received, particularly about the length of the fish and its reaction to the tags.

### Factors Affecting Number of Returns

The single factor that most markedly affected return percentages was the tags themselves. In the alternate experiments the discs yielded an overall percentage of 13.6 vs. 7.2 percent for the Lea tags. The cumulative number and percentage of returns by ten-week periods show that the discs give consistently better results regardless of the time the fish is at large between tagging and recovery, and that this difference becomes even more marked after the first year (Table 2). These results are in general agreement with those obtained by Canadian scientists in similar experiments (McCracken, contribution No. 16), but diametrically opposed to results obtained by English workers in the Barents Sea (Trout, 1958). An important difference in the English work was the methods of attachment of the two tag types — in the Barents Sea the Petersen discs were attached on the opercle and the Lea tags on the dorsum. This suggests that the place of attachment may be more important than the tag type itself.

Table 2

**Alternate tagging experiment: time at large, with accumulated number and percentage of returns by ten-week periods for the two types of tags used**

| Weeks out | Petersen discs | | Lea tags | |
|---|---|---|---|---|
| | Numbers returned | Accumulated Percentage | Numbers returned | Accumulated Percentage |
| 0—10 | 17 | 2.7 | 8 | 1.3 |
| 11—20 | 13 | 4.7 | 8 | 2.5 |
| 21—30 | 8 | 6.0 | 10 | 4.1 |
| 31—40 | 7 | 7.1 | 6 | 5.0 |
| 41—50 | 16 | 9.6 | 9 | 6.4 |
| 51—60 | 4 | 10.3 | 1 | 6.6 |
| 61—70 | 3 | 10.8 | 1 | 6.7 |
| 71—80 | 1 | 10.9 | 2 | 7.0 |
| 81—90 | 2 | 11.2 | — | 7.0 |
| 91—100 | 7 | 12.3 | — | 7.0 |
| 101—110 | 3 | 12.8 | — | 7.0 |
| 111—120 | 2 | 13.1 | — | 7.0 |
| 121—130 | 2 | 13.4 | 1 | 7.2 |
| 131—140 | — | 13.4 | — | 7.2 |
| 141—145 | 1 | 13.6 | — | 7.2 |

There is a marked difference in recoveries obtained from tagging fish of different sizes, as evidenced by the mean size at tagging and the mean size (at tagging) of the recovered fish (Table 3). It would seem an expensive use of time and effort to tag otter-trawl-caught cod less than 40 centimetres in length (of the three recoveries, two were 39 centimetres long). Apparently with these tags and techniques, tagging and/or handling mortality is high enough in small fish to preclude any substantial returns.

Table 3

**Alternate tagging experiment: percent return by sizes in 10 centimetre groups at tagging**

| Size group (cm) | Tagged | | | Returned | | | |
|---|---|---|---|---|---|---|---|
| | Disc | Lea | Total | Disc | Lea | Total | % |
| <40 .... | 68 | 78 | 146 | 3 | 0 | 3 | 2.0 |
| 41—50 .... | 125 | 111 | 236 | 12 | 4 | 16 | 6.8 |
| 51—60 .... | 89 | 107 | 196 | 16 | 7 | 23 | 11.7 |
| 61—70 .... | 77 | 83 | 160 | 14 | 10 | 24 | 15.0 |
| 71—80 .... | 109 | 92 | 201 | 14 | 8 | 22 | 10.9 |
| 81—90 .... | 80 | 89 | 169 | 14 | 10 | 24 | 14.2 |
| 91—100 .... | 45 | 41 | 86 | 6 | 4 | 10 | 11.6 |
| >100 .... | 32 | 24 | 56 | 6 | 3 | 9 | 16.1 |

The Chatham tagging and the spring tagging on Georges Bank provide a reasonably good comparison of the two methods of capture used in these experiments. The Chatham tagging was done from a commercial line trawler in February and March, and the Georges Bank work was done from the *Albatross III* operating as an otter trawler in March and April. Size groups at tagging and recaptured fish (sizes at tagging) are shown in Table 4. Although the Petersen discs yielded superior percentages of returns in the alternate tagging, and the Georges Bank experiments show

Table 4
**Comparison of returns by sizes at tagging from Georges Bank spring alternate tagging and Chatham tagging**

| Size group (cm) | Petersen discs Georges Bank Number tagged | Number returned | % | Lea tags Georges Bank Number tagged | Number returned | % | Lea tags Chatham Number tagged | Number returned | % |
|---|---|---|---|---|---|---|---|---|---|
| <41 | 0 | — | — | 0 | — | — | 71 | 10 | 14.1 |
| 41—50 | 1 | 1 | — | 0 | — | — | 228 | 56 | 24.6 |
| 51—60 | 5 | 1 | 20.0 | 7 | 1 | 14.3 | 255 | 68 | 26.7 |
| 61—70 | 28 | 10 | 35.7 | 25 | 4 | 16.0 | 211 | 50 | 23.7 |
| 71—80 | 54 | 9 | 16.7 | 56 | 5 | 8.9 | 136 | 38 | 27.9 |
| 81—90 | 61 | 11 | 18.0 | 62 | 6 | 9.7 | 62 | 11 | 17.7 |
| 91—100 | 38 | 6 | 15.8 | 35 | 3 | 8.6 | 24 | 4 | 16.7 |
| >100 | 31 | 6 | 19.4 | 20 | 3 | 15.0 | 22 | 3 | 13.6 |

that this is true for all sizes of fish, line-trawl-caught fish marked with Lea tags yielded higher returns than otter-trawl-caught fish in many size categories, and also gave much better returns for fish of less than 50 centimetres, than did the otter trawl.

Thus line trawling appears a far superior method of capture for tagging cod regardless of tag type, either because of the inherent difference in the gear or because of the shallower depths fished. (In these experiments, the line trawl was fished at 6—25 fathoms while the otter trawl was fished at 40—65 fathoms.)

When the time of year that each of the tagging operations was performed is compared with the percentage of returns, it is obvious that, other things being equal, at least twice as many returns are obtained from tagging in the spring than at any other time. This is further borne out in other cod marking experiments performed from 1955 to 1959 but not reported here. The reason for this is probably because of the cold surface temperatures associated with the relatively isothermal conditions prevailing in spring in the area, so that the physiological insult of being caught and subjected to reduced pressures, increased light, and air exposure is not further aggravated by adverse temperature effects. It would seem that if the time of year for tagging in most areas is optional, spring would be best, but that if tagging must be done at another time, allowance for higher tagging mortality should be made in any subsequent calculations.

Analysis of returns from tagging haddock during some of the same operations (and during others) shows that there can be marked differences in percentage of returns from fish tagged at the same time and under identical conditions by different operators. Apparently some biologists and technicians are more skilful in eliminating fish that appear to be bad risks and/or in their handling of the fish which they tag. In these experiments there are insufficient data to demonstrate this phenomenon, since I did nearly 85% of the tagging myself, but this also is a factor to be considered in mortality calculations when more than one individual has done the marking.

**Factors Affecting Quality of Returns**

While sufficient numbers of returns are essential to any marking experiment, a factor sometimes neglected, particularly in the original planning of the experiment, is the *quality* of the return. There is a vast difference in value between a tag found in a fish chowder and a tag found by an alert co-operative fisherman who furnishes exact information about time, place, etc. Best is the return where the fisherman has been interviewed by a scientist or technician who has reminded him of various details he might have forgotten and who has had the opportunity to examine the fish for precise measurement, weight, condition, etc. Of course, various factors can affect the quality of the return, and some of these have been examined with relation to these experiments.

An important consideration in evaluating fish marks is the visibility to the captor. It is of little avail to mark fish if the mark is not usually found early enough to yield useful information about time and place of capture, etc. With this in mind, the way in which the tags were first discovered was analyzed (Table 5). The Lea tag has a higher visibility to the fisherman, as might be expected. Lea tags were discovered either when caught or shortly afterward on board the vessel about 55% of the time, while the Petersens were thus discovered only about 40% of the time. Although better and more reliable information is obtained from such early recoveries, the superiority of the Lea tag in this respect is not sufficient to outweigh the advantage of the discs in overall recoveries — in other words, in numbers, more Petersen discs were found early than Lea tags. An interesting point in this consideration is the much larger percentage of discs found while processing the fish — perhaps the reason for this is that it is virtually impossible to fillet a fish bearing such a tag without the knife striking the wire passing through the dorsal muscles.

Table 6 shows three important bits of information desired with tag return, and the varying degrees of precision with which they were obtained from the

Table 5
**Alternate tagging experiment: analysis of when the tags were discovered on the fish**

| When discovered | Petersen discs Number | % | Lea tags Number | % |
|---|---|---|---|---|
| 1. When caught ..... | 13 | 15.1 | 10 | 21.7 |
| 2. On board ..... | 21 | 24.4 | 15 | 32.6 |
| 3. Unloading ..... | 5 | 5.8 | 2 | 4.3 |
| 4. Processing ashore .... | 20 | 23.3 | 7 | 15.2 |
| 5. In market ..... | 11 | 12.8 | 6 | 13.0 |
| 6. By consumer ..... | 0 | 0 | 0 | 0 |
| 7. Unknown or other ... | 16 | 18.6 | 6 | 13.0 |

recaptures made by various vessels and gear. It was always possible to make some reasonable estimate of the date of recapture, if only from the postmark on the envelope in which the tag came, but an inspection of the table shows that it was difficult to get from large and medium otter trawlers the exact date of recapture. This is undoubtedly due to the longer trips made by these vessels, but even this is not serious, for the date can usually be fixed with reasonable precision within a week or two.

Concerning location of recapture, the large and medium otter trawlers are the major offenders in respect of completely unknown locations. This is because of their propensity for ranging over wide areas in a single trip — a tagged individual not found until the fish are being or have been unloaded can often not be traced back to a particular fishing location. Line trawlers also show some serious discrepancies, because of the tendency of line trawl skippers either to neglect to mention location or to give it in terms of some local name not recorded on standard charts.

When it comes to useful measurement of the size of the recaptured fish, the otter trawlers as a group are far ahead of all other vessels and gear for producing good information; the majority of returns from otter trawlers produced a reliable measurement. This is probably not because of the nature of the vessels or their crews, but simply because they tend to land in the larger ports, where a technician is on hand to receive and measure the tagged fish.

### Conclusions

1. Alternate tagging experiments, using Petersen discs on stainless wire through the dorsal muscles and Lea tags internally anchored, demonstrate the marked superiority of the former technique over the latter, at least for cod in the southern part of the ICNAF Convention Area. The advantage of the discs over the Lea tags is approximately 2:1 in return percentages, although there is a suggestion in comparison with other work that the place of attachment may be more important than the tag *per se*.

2. The use of either of these marking methods on otter-trawl-caught cod less than 40 centimetres in length yields very low returns (2%).

3. The line trawl was demonstrated as a superior method of capture for marking, particularly for smaller cod, although it is not entirely clear whether this is due to the gear itself or to the shallower depth fished.

4. Other things being equal, spring appears to be the best time of year for marking cod, probably due to hydrographic conditions.

5. Although these experiments do not demonstrate it, the skill of the operators, if there are more than one, is a factor to be considered in evaluating returns.

6. The Lea tag as used in this work is apparently more visible to the fisherman than the Petersen discs. When a tag is missed aboard the vessel it is more likely to be noticed soon afterwards if it is of a type which interferes with the work of processing the fish for market.

7. There is a marked difference in the quality of information received with tag returns from different sorts of fishing vessels. Generally the best information is received where it is possible for a trained person to interview the fishermen and to examine the fish.

Table 6
**Number of returns with varying degrees of precision of information received with tag, from 1957 cod tagging experiments, classified by gear of recapture**

| Gear | Date Known | Date Estimated | Location Known | Location Estimated | Location Unknown | Size of fish at capture Known | Size of fish at capture Estimated | Size of fish at capture Unknown |
|---|---|---|---|---|---|---|---|---|
| Hand-line ..... | 23 | 3 | 24 | 2 | 0 | 12 | 0 | 14 |
| Line trawl ..... | 90 | 3 | 82 | 11 | 0 | 20 | 3 | 70 |
| Hand-line or Line trawl ..... | 10 | 2 | 10 | 2 | 0 | 0 | 0 | 12 |
| Otter trawler, large ..... | 38 | 28 | 55 | 10 | 1 | 37 | 0 | 29 |
| Otter trawler, medium ..... | 60 | 66 | 121 | 4 | 1 | 68 | 0 | 58 |
| Otter trawler, small ..... | 51 | 2 | 50 | 3 | 0 | 26 | 0 | 27 |
| Otter trawler, size unknown .... | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| Sink gill net ..... | 13 | 0 | 12 | 1 | 0 | 8 | 0 | 5 |
| Unknown ..... | 28 | 15 | 23 | 4 | 16 | 3 | 1 | 39 |

### Summary

During 1957, 2440 cod were tagged, 1291 of these ernately with Lea tags anchored internally and ersen discs through the dorsal musculature. e alternate tagging experiments indicate clearly superiority of the latter method. In a comparison line-trawling vs. otter-trawling as a method of ture for tagging, the line appears to yield better ilts, particularly for smaller fish. The quality of returns, that is the amount of accurate information received with the tag, is shown to be highly variable, although at least some of the reasons for the variability are subject to analysis.


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# AGE AND LENGTH COMPOSITION OF THE SARDINE CATCH OFF THE PACIFIC COAST OF THE UNITED STATES AND MEXICO IN 1960-61 [1]

by

ROBERT S. WOLF

U. S. Bureau of Commercial Fisheries

and

ANITA E. DAUGHERTY

Marine Resources Operations

California Department of Fish and Game

## INTRODUCTION

This is the 15th report in a series on age and length composition of the catch of Pacific sardines, *Sardinops caeruleus* (Girard), off the Pacific coast of North America. These have been prepared on a seasonal basis since the 1941-42 season (Wolf and Daugherty, 1961).

We wish to acknowledge the valuable assistance given by Clark Blunt of the California Department of Fish and Game and by Makoto Kimura of the U. S. Bureau of Commercial Fisheries.

## THE FISHERY

During the 1960-61 commercial season, 26,943 tons of sardines were taken by the California fishery in central and southern California. In addition the Mexican fishery off Baja California took 19,763 tons during calendar 1961 for a total commercial sardine catch of 46,706 tons.

### Central California

The 1960-61 sardine season in central California (Point Arguello north to Point Arena) began on August 1, 1960, and ended on December 31, 1960. Within this period fish were landed during only three lunar months or dark-of-the-moon periods (Table 1)—"August," "September," and "October"—because a price dispute kept the fleet from fishing until August 16 and because fish became unavailable after "October." Lunar months are set in quotation marks to distinguish them from the calendar months they approximate. During "August" 1,876 tons were landed (approximating 91 percent of the season's catch from this region), during "September" 150 tons, and during "October" 37 tons. The seasonal total of 2,063 tons is small when compared with 15,418 tons and 24,614 tons taken during the 1959-60 and 1958-59

[1] Submitted for publication, June 1963.

TABLE 1

**Calendar Dates of Lunar Months During 1960**

| *Lunar month* | *Lunar period* | *Dates* |
|---|---|---|
| "January" | 497 * | December 15 (1959)-January 12 |
| "February A"† | 498 | January 13-February 10 |
| "February B" | 499 | February 11-March 11 |
| "March" | 500 | March 12-April 10 |
| "April" | 501 | April 11-May 10 |
| "May" | 502 | May 11-June 8 |
| "June" | 503 | June 9-July 8 |
| "July" | 504 | July 9-August 6 |
| "August" | 505 | August 7-September 5 |
| "September" | 506 | September 6-October 5 |
| "October" | 507 | October 6-November 3 |
| "November" | 508 | November 4-December 3 |
| "December" | 509 | December 4-January 1 (1961) |

* Lunar months have been numbered serially since "November" 1919.
† Because lunar months are shorter than calendar months it is necessary to add an additional lunar month every 3 years.

seasons, and extremely small compared to the 435,000+ tons taken during the 1940-41 season.

The earliest catches during "August" were made by lampara boats operating close to the southern edge of Monterey Bay. Later in the dark some sardines were taken from around Cape San Martin and Lopez Point. During the remaining two darks, the central California catch came almost entirely from the Morro Bay area.

At the beginning of the season 28 boats were involved in the fishery. This total included 11 large purse seiners, two small purse seiners, and 15 lampara boats. The sardine fishing efforts of the latter varied directly with the immediate availability of sardines as these vessels are readily adaptable to other types of fishing. As the season progressed and sardines became less available in central California the purse-seine fleet gradually shifted to Port Hueneme in southern California. From mid-"September" until the end of the season all the purse seiners in the central California fleet spent some time fishing sardines in southern California.

The ex-vessel price of fish was $35 per ton. When trucking fish from port of landing to cannery (sometimes from southern California ports to central California canneries) was necessary, the cost of trucking was divided equally between the boat or boats involved and the cannery.

Seven canneries processed sardines in central California, one each in San Francisco and Moss Landing, and five in Monterey. These plants handled approximately 6,500 tons of fish—over two-thirds trucked from southern California.

### Southern California

A total of 24,880 tons of sardines was landed in southern California (Point Arguello south to the Mexican border) during the season which began on September 1, 1960, and ended concurrently with the central California season on December 31, 1960. This tonnage was considerably under the 78,007 tons taken during 1958-59, but slightly over the 20,335

tons landed during 1959-60. During the 5 days of "August" remaining after the season began, 809 tons were landed. "September" was high with 10,779 tons taken; in "October" 7,873 tons were landed, in "November" 4,130 tons, and in "December" 1,289 tons.

Most of the southern California sardine catch came from around the Channel Islands, mainly Santa Cruz and Anacapa and to a lesser extent San Nicolas and Santa Rosa. Small amounts were taken from around Point Dume, on Santa Monica Bank, and in Santa Monica Bay which was open to bait net (small lampara) commercial fishing from October 1 to December 31 for the second successive season. Additional small amounts came from off Santa Catalina and San Clemente Islands, and from Cortez Bank. Only a few small catches came from the Newport-Huntington Beach area, south of San Pedro.

The southern California fleet consisted of 58 large purse seiners and 31 small purse seiners and lampara boats. Of these, 11 large seiners and 2 small seiners fished in central California during the early part of the season. The total California fleet was the smallest to fish sardines in over 30 years. No boats from the Pacific Northwest took part in the fishery.

The price in southern California had been set the previous July at $35 a ton but trucking charges, where necessary, were paid by the boat.

One cannery operated at Oxnard utilizing fish landed at Port Hueneme; six operated in the Los Angeles-Long Beach harbor area.

### Baja California

The sardine fishery off Baja California, Mexico, is a year-round enterprise. We have divided the year into two parts, January 1 to August 31, and September 1 to December 31, so that the latter part may be compared with the southern California season. During the first part, the "interseason," 12,323 tons were landed and during the second part, the "season," 7,440 tons were landed.

The 1960 Baja California sardine fishery ranged from the U.S.-Mexican border south to about Punta Abreojos (approximately 400 miles). Sardines in commercial quantity are present in at least part of this range throughout the year. Three ports, each with one or more canneries, are located within its limits. Ensenada, located 60 miles below the border, added a cannery during 1960 for a total of six packing sardines in that city. It is the largest fishing port in Baja California, and prior to 1958 produced over 80 percent of the annual sardine pack. Since 1958, however, the sardine center of abundance has gradually shifted south so that in 1960 the Cedros Island cannery produced nearly one-half of the total Baja California sardine pack. This cannery is located almost 300 miles south of the border and the range of its vessels determines the fishery southern limit. A cannery at San Quintin Bay, about halfway between the above two ports, packs sardines only when available in the immediate vicinity of the bay.

In 1960, the Baja California fishing fleet consisted of 40 vessels that spent some part of their time fishing sardines. Thirty-one of these were generally located at Ensenada, eight at Cedros Island, and one at San Quintin. Two of the boats based at Ensenada also landed fish at Cedros

Island during part of the year. The fleet consisted of large and small purse seiners, most of them locally owned, but occasionally was augmented by American boats from San Diego and San Pedro. (The extent to which American boats contribute to the sardine catch in Mexican ports is not known.) Many of the large vessels are now equipped with refrigerated holds which allows them to fish for longer periods and at greater distances from port than previously.

The amount paid to fishermen for sardines canned in Baja California varied with their operational status. Crews under contract to canneries, fishing on cannery-owned vessels, received up to 188.75 pesos (U. S. $15.10) per metric ton (2,205 lbs.). Privately owned vessels, usually American owned and operated, received up to 410.00 pesos (U. S. $32.80) per metric ton. Though the prices quoted are the maximums paid by the canneries, the range of prices was slight so the given prices are close to the average for the year.

## AGE AND LENGTH COMPOSITION

During the commercial sardine season, 1,050 fish from central California and 4,100 fish from southern California were randomly selected from the catch in lots of 50 and measured (standard length) to the nearest millimeter. When these measurements were summarized and plotted (Figure 1) two separate size groups were evident in central California, and a single size group in southern California. Lengths of fish from central California ranged from 156 to 186 mm for the smaller group, and from 206 to 264 mm for the larger group. In southern California fish ranged from 164 to 250 mm.

Approximately one-fifth of the fish sampled were randomly selected for aging. Scales from the mid-lateral region of each fish were removed, prepared, and examined for annual markings. The central California age sample of 223 fish ranged from 158 to 264 mm and contained five year-classes: 1955, 1956, 1957, 1958, 1959 (Table 2). The southern California age sample of 817 fish ranged from 174 to 246 mm and included six year-classes: 1953 and 1955 through 1959 (Table 3). The Baja California catch was not sampled during the latter half of calendar year 1960.

During the interseason, scattered samplings of sardines were made in both central and southern California. These interseason catches appear to represent a random sampling of sardines present in the fishing areas during the offseason. As during the commercial season, age compositions of interseason samples were obtained from one-fifth of the fish measured. Plots of length and age compositions of samples, summarized by lunar months for both interseason and regular season samples taken in central and southern California, are presented with similar plots of interseason samples from Baja California (Figure 2).

In central California, samples were obtained during nine consecutive lunar months ("February B" through "October"). The modal lengths of the group of larger fish showed an advance from 216 to 222 [2] mm

[2] This and subsequent mode changes cited in the text are presented as even numbers adjusted to 2 mm intervals because sardine lengths are normally tabulated this way. When these changes appear in Figure 2, they are not so precisely portrayed because of the necessity to plot the length frequency polygons on 10 mm intervals in order to present smooth curves.

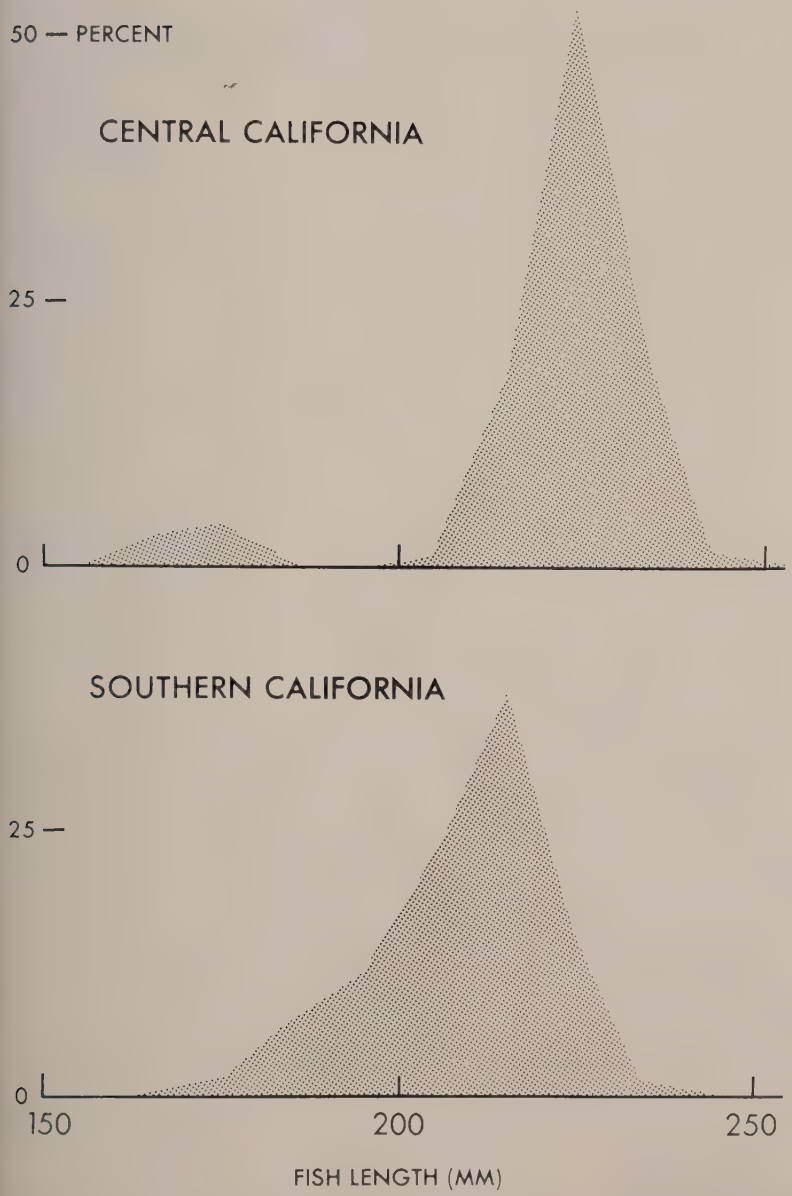


FIGURE 1. Percentage length composition of sardines sampled during the 1960-61 commercial season by region of capture. Data are plotted at 10 mm intervals.

TABLE 2

**Length Composition of Year-classes in Sardine Samples from the Central California Commercial Catch, 1960-61 Season**

| Age | 0 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| Year-class | 1960 | 1959 | 1958 | 1957 | 1956 | 1955 | Total |
| Standard length mm. | | | | | | | |
| 158 | -- | 2 | -- | -- | -- | -- | 2 |
| 160 | | | | | | | |
| 162 | -- | 3 | -- | -- | -- | -- | 3 |
| 164 | -- | 1 | -- | -- | -- | -- | 1 |
| 166 | -- | 2 | 1 | -- | -- | -- | 3 |
| 168 | -- | 2 | 1 | -- | -- | -- | 3 |
| 170 | -- | 3 | 3 | -- | -- | -- | 6 |
| 172 | -- | 1 | 1 | -- | -- | -- | 2 |
| 174 | -- | 1 | -- | -- | -- | -- | 1 |
| 176 | -- | -- | -- | -- | -- | -- | -- |
| 178 | -- | 1 | -- | -- | -- | -- | 1 |
| 180 | -- | -- | 1 | -- | -- | -- | 1 |
| 182 | -- | 1 | -- | -- | -- | -- | 1 |
| 184 | -- | 1 | -- | -- | -- | -- | 1 |
| 208 | | | | | | | |
| 210 | -- | -- | -- | -- | 1 | -- | 1 |
| 212 | -- | -- | -- | 1 | 1 | -- | 2 |
| 214 | -- | -- | -- | 3 | 2 | -- | 5 |
| 216 | -- | -- | -- | 2 | 1 | -- | 3 |
| 218 | -- | -- | -- | 6 | 6 | -- | 12 |
| 220 | -- | -- | -- | 5 | 4 | -- | 9 |
| 222 | -- | -- | -- | 17 | 6 | 1 | 24 |
| 224 | -- | -- | 2 | 16 | 7 | 1 | 26 |
| 226 | -- | -- | 2 | 13 | 2 | -- | 17 |
| 228 | -- | -- | 1 | 16 | 8 | 1 | 26 |
| 230 | -- | -- | -- | 17 | 10 | 1 | 28 |
| 232 | -- | -- | -- | 9 | 5 | -- | 14 |
| 234 | -- | -- | -- | 4 | 8 | 2 | 14 |
| 236 | -- | -- | -- | 3 | 2 | -- | 5 |
| 238 | -- | -- | -- | 4 | 1 | 1 | 6 |
| 240 | -- | -- | -- | 1 | 2 | 1 | 4 |
| 242 | | | | | 1 | | 1 |
| 264 | -- | -- | -- | -- | 1 | -- | 1 |
| Totals | -- | 18 | 12 | 117 | 68 | 8 | 223 |
| Mean lengths | -- | 169 | 194 | 226 | 227 | 231 | 220 |

TABLE 3

**Length Composition of Year-classes in Sardine Samples from the Southern California Commercial Catch, 1960-61 Season**

| Age | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|---|
| Year class | 1960 | 1959 | 1958 | 1957 | 1956 | 1955 | 1954 | 1953 | Total |
| Standard length mm. | | | | | | | | | |
| 174 | | | 2 | | | | | | 2 |
| 176 | | | | 1 | | | | | 1 |
| 178 | | | 1 | | | | | | 1 |
| 180 | | 1 | 2 | | | | | | 3 |
| 182 | | | 6 | 5 | | | | | 11 |
| 184 | | 1 | 11 | 6 | | | | | 18 |
| 186 | | 1 | 6 | 6 | | | | | 13 |
| 188 | | | 3 | 5 | | | | | 8 |
| 190 | | | 6 | 5 | 1 | | | | 12 |
| 192 | | 1 | 7 | 7 | 1 | | | | 16 |
| 194 | | 2 | 9 | 8 | | | | | 19 |
| 196 | | | 6 | 4 | | | | | 10 |
| 198 | | | 11 | 12 | 1 | | | | 24 |
| 200 | | | 12 | 12 | 5 | | | | 29 |
| 202 | | | 11 | 4 | 5 | | | | 20 |
| 204 | | | 10 | 18 | | | | | 28 |
| 206 | | | 11 | 21 | 2 | 1 | | | 35 |
| 208 | | | 13 | 22 | 7 | | | | 42 |
| 210 | | | 8 | 30 | 12 | 1 | | | 51 |
| 212 | | 1 | 15 | 41 | 10 | 4 | | | 71 |
| 214 | | | 8 | 40 | 15 | | | | 63 |
| 216 | | | 8 | 33 | 14 | 1 | | | 56 |
| 218 | | | 2 | 42 | 18 | 1 | | | 63 |
| 220 | | | 8 | 42 | 20 | 1 | | | 71 |
| 222 | | | 2 | 33 | 16 | | | | 51 |
| 224 | | | 1 | 22 | 14 | | | | 37 |
| 226 | | | 3 | 14 | 10 | | | | 27 |
| 228 | | | | 6 | 5 | | | | 11 |
| 230 | | | 1 | 6 | 5 | | | | 12 |
| 232 | | | | 2 | 2 | | | | 4 |
| 234 | | | | 2 | 1 | | | | 3 |
| 236 | | | | 1 | 1 | | | | 2 |
| 238 | | | | 1 | | | | | 1 |
| 240 | | | | | | | | | |
| 242 | | | | | | | | | |
| 244 | | | | | | | | 1 | 1 |
| 246 | | | | | | 1 | | | 1 |
| Totals | | 7 | 183 | 451 | 165 | 10 | | 1 | 817 |
| Mean lengths | | 192 | 202 | 212 | 217 | 216 | | | 211 |

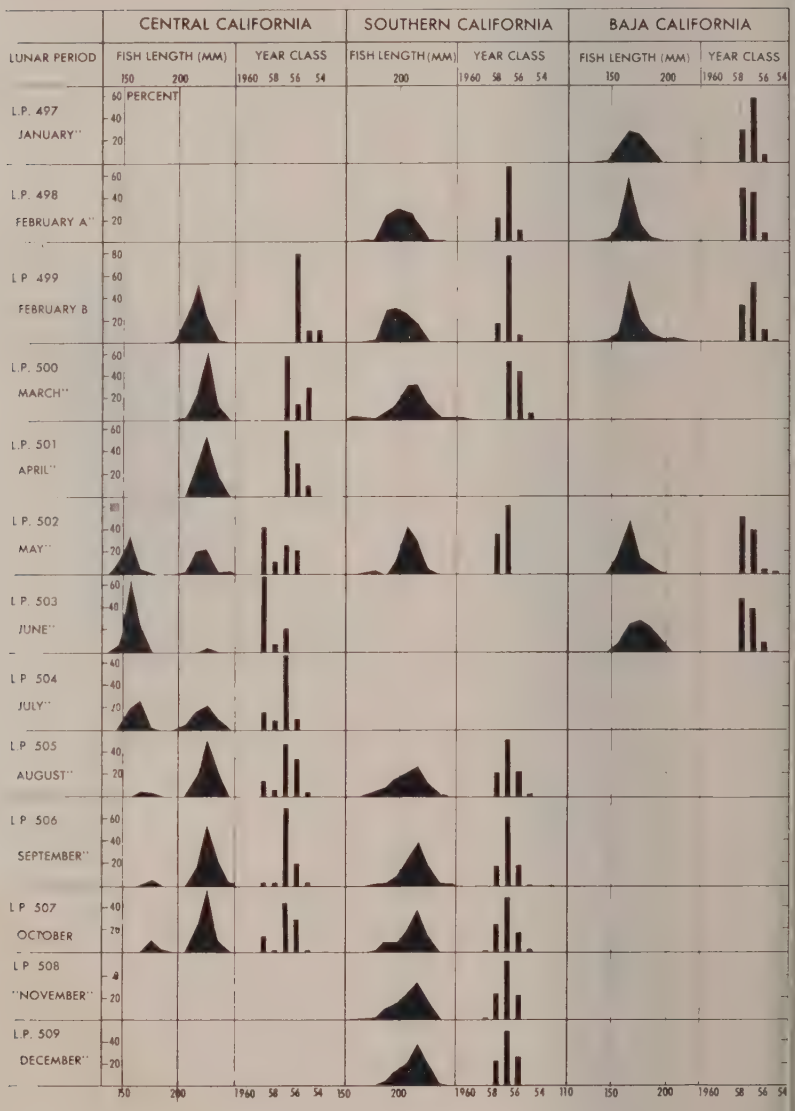


FIGURE 2. Percentage length composition of sardines sampled during the 1960-61 commercial season by region of capture. Data are plotted at 10 mm intervals.

between "February B" and "March" but no increase subsequent to this. A group of smaller fish became evident in "May" and its mode had advanced 24 mm (154-178) by "October." The small group was made up of 1959 class fish together with a few 1958's. The larger group contained mostly 1957, 1956, and 1955 class fish plus some 1954's in "February B."

In southern California, samples were obtained in "February A," "March," "May," and in all the lunar months of the commercial season. There were two length groups present here also but they were not so distinct as in central California. The mode of the larger fish advanced from 196 to 220 mm between "February A" and "December." The mode of the smaller size-group that appeared in "March" advanced into the range of the larger size-group by "December." The age composition of the large size-group consisted principally of 1958, 1957, and 1956 class fish. A few 1955 class fish were evident in "March" and in "August" through "October." Fish of an age corresponding to the small length-group (1959 class) appeared only in "October" and "November."

Baja California interseason samples were taken from "January" through "February B," and in "May," and "June." There was a single mode which remained at 166 mm from "January" through "May," then advanced to 176 mm in "June." Though this mode was relatively constant throughout the period of sampling, the age composition of fish within the distributions varied. The 1958 and 1957 classes alternated in dominance but together made up the bulk of the catch. (Variations in the proportions of year-classes within essentially alike length-frequency summaries are not unusual.) Lesser amounts of the 1956 and 1955 classes were also present.

Age and length data for all months sampled during the Baja California interseason were based on 621 age readings (Table 4). The average length of fish at any age is considerably less in Baja California than in southern or central California.

To estimate the year-class composition of a region's catch during any lunar month, two things are required. The first is an estimate of the number of fish in the landings during the lunar month, the second is a summary of the year-class composition of all fish sampled and subsequently aged during the same lunar month. (An estimate of the total number of fish landed is determined by dividing the total weight of fish landed by the average weight of fish sampled.) This total can then be broken down into year-classes in the same proportions as in the summary of fish that were actually aged. More precise details of the method are given by Felin and Phillips (1948, p. 11).

During the commercial season the average fish caught in central California weighed .3458 pounds and in southern California .2700 pounds. The number of fish caught in Baja California during the season was estimated using the average fish weight of .1596 calculated from the "June" interseason samples, the last lunar month in which the catch was sampled. The "June" average weight was slightly higher than the average weight of .1569 pounds calculated over the entire interseason.

Estimates of numbers of fish in each year-class have been made for the central California commercial season catch, and for the catch off both southern California and Baja California during the southern California season (Table 5). Sardines of the 1957 class made up over half of the season's catch in both California regions. In central California an additional third came from the 1956 class while minor amounts of 1959, 1958, 1955, and 1954's constituted the remainder. In southern

TABLE 4

**Length Composition of Year-classes in Sardine Samples from the Baja California Interseason Catch**

| Age | 0 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| Year-class | 1960 | 1959 | 1958 | 1957 | 1956 | 1955 | Total |
| Standard length mm. | | | | | | | |
| 140 | -- | -- | 1 | -- | -- | -- | 1 |
| 142 | -- | -- | -- | -- | -- | -- | -- |
| 144 | -- | -- | 1 | -- | -- | -- | 1 |
| 146 | -- | -- | 1 | -- | -- | -- | 1 |
| 148 | -- | -- | 1 | -- | -- | -- | 1 |
| 150 | -- | -- | 3 | -- | -- | -- | 3 |
| 152 | -- | -- | 1 | -- | -- | -- | 1 |
| 154 | -- | -- | 5 | 1 | -- | -- | 6 |
| 156 | -- | -- | 7 | -- | -- | -- | 7 |
| 158 | -- | -- | 10 | 2 | -- | -- | 12 |
| 160 | -- | -- | 24 | 1 | -- | -- | 25 |
| 162 | -- | -- | 25 | 7 | -- | -- | 32 |
| 164 | -- | -- | 25 | 12 | 1 | -- | 38 |
| 166 | -- | -- | 37 | 13 | -- | -- | 50 |
| 168 | -- | -- | 40 | 21 | -- | -- | 61 |
| 170 | -- | -- | 20 | 26 | -- | -- | 46 |
| 172 | -- | -- | 9 | 10 | -- | -- | 19 |
| 174 | -- | -- | 22 | 21 | -- | -- | 43 |
| 176 | -- | -- | 8 | 19 | 4 | -- | 31 |
| 178 | -- | -- | 8 | 17 | 3 | -- | 28 |
| 180 | -- | -- | 7 | 15 | 5 | -- | 27 |
| 182 | -- | -- | 4 | 16 | 4 | 1 | 25 |
| 184 | -- | -- | 5 | 16 | -- | -- | 21 |
| 186 | -- | -- | 4 | 14 | 2 | -- | 20 |
| 188 | -- | -- | 3 | 18 | 4 | 1 | 26 |
| 190 | -- | -- | 1 | 13 | 4 | 1 | 19 |
| 192 | -- | -- | 2 | 6 | 5 | -- | 13 |
| 194 | -- | -- | 1 | 11 | 5 | 2 | 19 |
| 196 | -- | -- | 1 | 9 | 2 | -- | 12 |
| 198 | -- | -- | -- | 9 | 2 | -- | 11 |
| 200 | -- | -- | -- | 1 | 1 | 1 | 3 |
| 202 | -- | -- | -- | 2 | 1 | -- | 3 |
| 204 | -- | -- | -- | 4 | 3 | 2 | 9 |
| 206 | -- | -- | -- | -- | -- | -- | -- |
| 208 | -- | -- | -- | -- | 2 | -- | 2 |
| 210 | -- | -- | -- | -- | 1 | 1 | 2 |
| 212 | -- | -- | -- | -- | 2 | -- | 2 |
| 214 | -- | -- | -- | -- | -- | -- | -- |
| 216 | -- | -- | -- | -- | -- | -- | -- |
| 218 | -- | -- | -- | -- | 1 | -- | 1 |
| Totals | -- | -- | 276 | 284 | 52 | 9 | 621 |
| Mean lengths | -- | -- | 168 | 179 | 191 | 196 | -- |

TABLE 5

**Age and Year-class Composition of the Sardine Catch in the 1960-61 season**

| | Catch | | Number of fish in thousands by age and year-class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Tons* | *Number* | *0* *1960* | *1* *1959* | *2* *1958* | *3* *1957* | *4* *1956* | *5* *1955* | *6* *1954* | *7* *1953* |
| Central California | | | | | | | | | | |
| "July" | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| "August" | 1,876 | 10,808 | -- | 499 | 528 | 5,512 | 3,770 | 432 | 67 | -- |
| "September" | 150 | 905 | -- | 30 | 18 | 646 | 175 | 18 | 18 | |
| "October" | 37 | 246 | -- | 27 | 12 | 126 | 76 | 5 | | |
| Total Central California | 2,063 | 11,959 | -- | 556 | 558 | 6,284 | 4,021 | 455 | 85 | -- |
| Percent | -- | 100.0 | -- | 4.7 | 4.7 | 52.4 | 33.7 | 3.8 | 0.7 | -- |
| Southern California | | | | | | | | | | |
| "August" | 809 | 6,391 | -- | 26 | 1,968 | 3,400 | 895 | 102 | -- | |
| "September" | 10,779 | 78,437 | -- | 1,082 | 14,770 | 46,898 | 15,036 | 541 | 55 | 55 |
| "October" | 7,873 | 57,036 | -- | 1,243 | 14,727 | 28,051 | 11,099 | 1,865 | 51 | |
| "November" | 4,130 | 32,387 | -- | 411 | 7,909 | 16,537 | 7,262 | 204 | 32 | 32 |
| "December" | 1,289 | 9,688 | -- | - | 2,215 | 5,038 | 2,435 | - | -- | |
| Total Southern California | 24,880 | 183,939 | -- | 2,762 | 41,589 | 99,924 | 36,727 | 2,712 | 138 | 87 |
| Percent | -- | 100.0 | -- | 1.5 | 22.6 | 54.3 | 20.0 | 1.5 | 0.1 | -- |
| Total California | 26,943 | 195,898 | -- | 3,318 | 42,147 | 106,208 | 40,748 | 3,167 | 223 | 87 |
| Percent | -- | 100.0 | -- | 1.7 | 21.5 | 54.3 | 20.8 | 1.6 | 0.1 | -- |
| Total Baja California* | 7,440 | 93,225 | -- | - | 46,053 | 37,290 | 9,323 | 559 | - | |
| Percent | -- | 100.0 | -- | -- | 49.4 | 40.0 | 10.0 | 0.6 | - | -- |
| TOTAL | 34,383 | 289,123 | -- | 3,318 | 88,200 | 143,498 | 50,071 | 3,726 | 223 | 87 |
| Percent | -- | 100.0 | -- | 1.2 | 30.5 | 49.6 | 17.3 | 1.3 | 0.1 | - |

*Period from September 1 to December 31—Aged with age composition of "June."

California, the 1958 and 1956 classes each supplied an additional one-fifth of the catch and the 1959, 1955, 1954, and 1953's each constituted small amounts. The Baja California catch was not sampled during the southern California season, therefore it was necessary to estimate the Baja California "seasonal" year-class composition totals using age composition data of the preceding "June" period. The results of the estimates show the 1958 and 1957 classes together made up nearly nine-tenths of the Baja California total. The remainder was overwhelmingly 1956 class fish but a few 1955's were present.

During the Baja California interseason, the year-class composition of the catch was similar to that derived for the "season" but here the 1958 and 1957 classes were almost equally abundant (Table 6).

TABLE 6

**Year-class Composition of the 1960 Interseason Sardine Catch Off Baja California**

| | *Catch* | | *Number of fish in thousands by year-class* | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Lunar month* | *Tons* | *Number* | *1960* | *1959* | *1958* | *1957* | *1956* | *1955* |
| "January" | 59 | 723 | -- | -- | 217 | 432 | 65 | 9 |
| "February A" | 872 | 11,739 | -- | -- | 5,635 | 5,165 | 939 | -- |
| "February B" | 1,600 | 22,313 | -- | -- | 7,363 | 12,050 | 2,454 | 446 |
| "March" * | 1,557 | 19,677 | -- | -- | 6,493 | 10,626 | 2,164 | 394 |
| "April" † | 739 | 8,742 | -- | -- | 4,555 | 3,497 | 463 | 227 |
| "May" | 1,996 | 25,181 | -- | -- | 13,119 | 10,072 | 1,335 | 655 |
| "June" | 1,437 | 17,997 | -- | -- | 8,890 | 7,199 | 1,800 | 108 |
| "July" ‡ | 3,268 | 40,749 | -- | -- | 20,130 | 16,300 | 4,075 | 244 |
| "August" ‡ | 795 | 9,911 | -- | -- | 4,897 | 3,964 | 991 | 59 |
| Total | 12,323 | 157,032 | -- | -- | 71,299 | 69,305 | 14,286 | 2,142 |
| Percent | -- | 100.0 | -- | -- | 45.4 | 44.1 | 9.1 | 1.4 |

* Aged with age composition of "February B".
† Aged with age composition of "May".
‡ Aged with age composition of "June".

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# The Movements of Walleyes Tagged as Yearlings in Lake Erie

David R. Wolfert

# The Movements of Walleyes Tagged as Yearlings in Lake Erie

David R. Wolfert
*U. S. Bureau of Commercial Fisheries, Sandusky, Ohio*

ABSTRACT

A total of 3,998 yearling walleyes, *Stizostedion vitreum vitreum* (Mitchill), were captured, tagged, and released along the south shore of western Lake Erie to determine their movements and their dispersal from a known nursery area. Four hundred ninety-nine recoveries were made over a period of 3 years. Tagged walleyes traveled primarily north toward the islands in the Western Basin during their first year of liberation, and in succeeding years moved progressively toward the extreme western end of the lake. Some walleyes were recaptured within 6 months in the Detroit River, Lake St. Clair, the St. Clair River, and southern Lake Huron, and the percentage of fish recaptured in these waters north of Lake Erie increased annually. Movement eastward into the Central and Eastern Basins of the lake appeared negligible. The greatest distance traveled by a marked walleye was 236 miles. The average distance traveled by all tagged fish was 25 miles.

## INTRODUCTION

The walleye, *Stizostedion vitreum vitreum* (Mitchill), has in the past been one of the principal species in the commercial and sport fisheries of Lake Erie. The commercial fishery for this species in the lake has declined from a production of 15,405,000 pounds in 1956 to a low of approximately 715,000 pounds in 1962. This decline has been accompanied by demands for intelligent management of the fishery to restore and sustain production. Studies of several aspects of the life history of the walleye were begun in 1957 to provide information essential to any management plan.

This report describes the results of an investigation of the movements and dispersal of walleyes of the 1959 year class that were captured as yearlings, tagged, and released along the south shore of the Western Basin of the lake. Marking operations were confined largely to the Western Basin because there is evidence that this area is the primary spawning area for the walleye in Lake Erie. Few walleyes are taken in other sections of the lake during the spawning season, and almost all small 0-group fish taken in experimental fishing gear are from the Western Basin.

Fortunately, the 1959 year class was stronger than any since 1954. Fish were available in 1960 as yearlings in much greater numbers than could have been obtained from earlier, weaker year classes.

Many studies of walleye movements have been conducted, but in Lake Erie they have been few. Doan (1942) tagged 1,248 walleyes in the Bass Islands area in 1938–40. Little knowledge of walleye movements was gained because only 22 were recovered. Walleye tagging in the Canadian waters of western Lake Erie in 1954 by the Ontario Department of Lands and Forests showed a pronounced eastward movement of the fish along the Canadian shore (Ferguson, 1957[1]). Extensive tagging by the Ohio Division of Wildlife in United States waters of the Western Basin in 1954 also indicated an eastward movement (unpublished data). Tagging studies in Lake Huron and Lake St. Clair in 1955 and 1956 have shown a seemingly random movement of walleyes between Lakes Huron and Erie through the Detroit River, Lake St. Clair, and the St. Clair River (Ferguson and Cummins, 1956; Ferguson, *op. cit.*).

The walleyes tagged by these earlier investigators were much older and larger than those marked in the present study. Few, if any, were younger than 2 full years, and most were still older; some were from spawning runs. The earlier tagging, furthermore, was carried out during years of peak walleye availability and production, whereas the preser

[1] Ferguson, R. G. (1957) Fish tagging studies in Lakes Erie, St. Clair, and Huron. Preliminary Rept. Ontario Dept. Lands and Forests, Div. of Researc 12 pp. (Mimeo.)

[2] Ferguson, R. G., and R. Cummins. (1956) Lak St. Clair fish tagging. Rept. to Lake Erie Fish Management Committee, 13 pp. (Mimeo.)

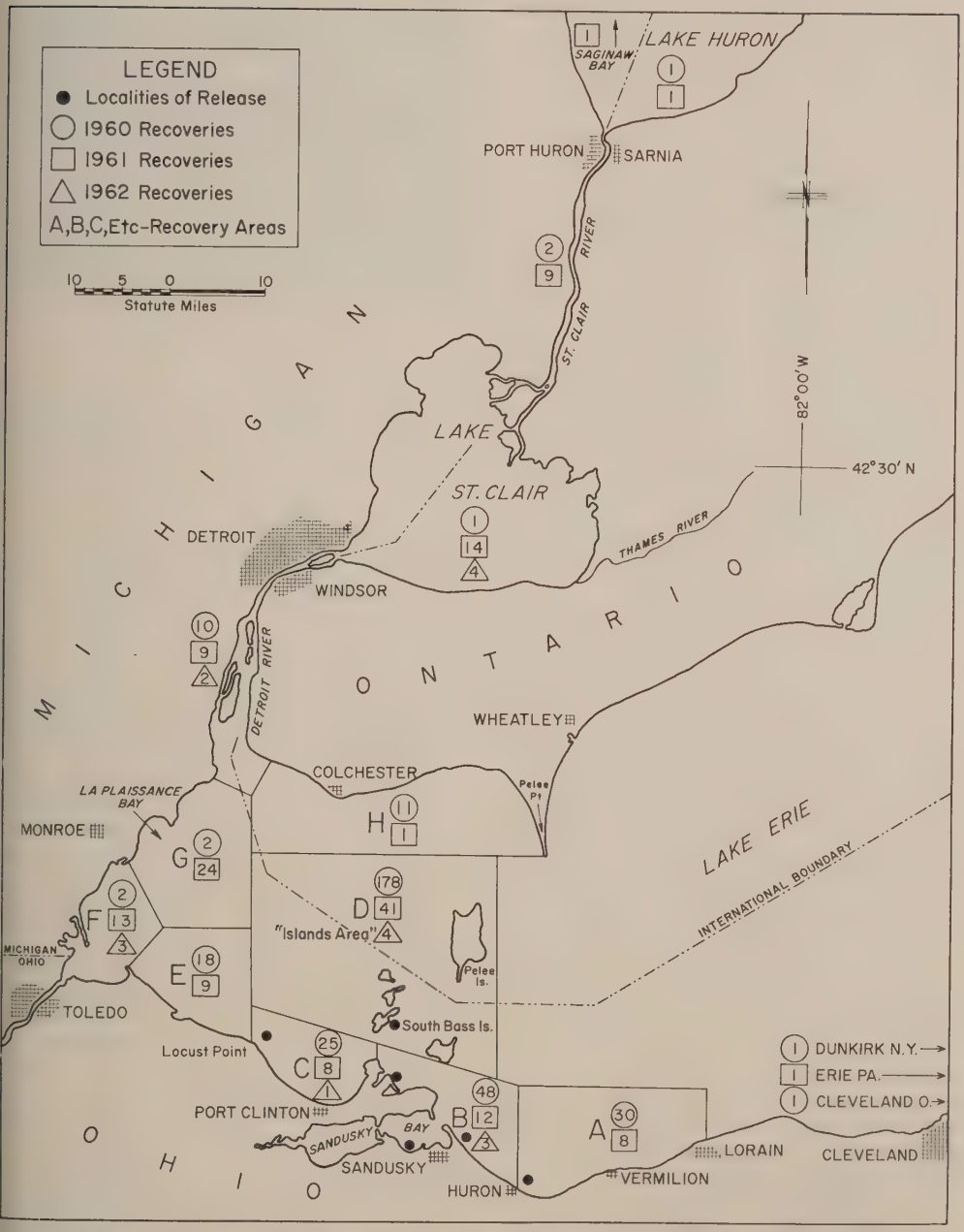


FIGURE 1.—Map of western Lake Erie, Lake St. Clair, southern Lake Huron, and connecting waters showing locations where tagged fish were released and numbers of fish recovered in various areas in each of three years after tagging.

study was conducted during a period of limited availability and low production. Because of these differences of fish size and of conditions in the lake, results from the earlier and the present study should not be compared in detail.

## METHODS AND MATERIALS

During April and May 1960, 3,998 yearling walleyes were tagged and released at six locations between Locust Point and Vermilion, Ohio, a distance of approximately 45 miles (Figure 1). Commercial trap netters and drag or haul seiners were catching these fish at this time in considerable numbers. The average total length of the yearlings (based on 502 measurements) was 10.5 inches (range, 8.3 to 12.2 inches), 2.5 inches below Ohio's legal commercial length. We accompanied the fishing boats and tagged the yearling walleyes prior to their release as "undersize" fish. Ninety-one percent of the tagged fish were obtained from trap nets and the remainder from seines.

A dart-type tag was used (Yamashita and Waldron, 1958). The head of the tag was manufactured of 3/64-inch solid nylon and was 3/4 inch long. The streamer section consisted of a 4-inch piece of yellow, size No. 18, neoprene tubing with a printed return address. The tag was loaded into a needle of 1/8-inch stainless-steel tubing, and both were dipped into 70 percent isopropyl alcohol immediately before insertion to attempt to reduce the probability of infection. The needle was inserted into the musculature at the anterior margin of the soft-rayed portion of the dorsal fin; care was taken to keep the barb of the tag parallel with the main axis of the body (Figure 2). The needle was then eased forward at an angle of 45 degrees to the main body axis so that the barb passed between the interneurals and was held firmly in place. The needle was withdrawn and the fish returned to the water.

The wound which the dart-type tag made did not appear to have harmful effects. No tagged fish that were recaptured were reported to have any evidence of fungus infection even when taken in shallow, warm water, such as Sandusky Bay in midsummer. The wound on recaptured fish usually appeared as an elliptical, irritated, or abraded area with a diameter of about 10 millimeters that surrounded the protruding portions of the tag. This area rarely penetrated deeper than the dermis, and no internal abscesses were seen. The nature of the wound is attributed to the almost continuous movement of the area of the fish's body in which the tag was inserted.

FIGURE 2.—Yearling walleye with dart-type tag inserted and ready for release.

The U. S. Bureau of Commercial Fisheries did not offer rewards for the return of tags from recaptured walleyes, but the Ontario Department of Lands and Forests paid both a reward for the returned tag and also the price of the fish if it was returned with the tag intact. Payment of rewards may have encouraged the return of a proportionately greater number of tags from Canadian than from United States waters. Most Canadian returns were accompanied by data listing not only date and location of recapture, but length, weight, sex, condition of gonads, stomach analysis, and scale sample. The return of tags was encouraged by personal interviews with commercial fishermen and by newspaper publicity directed at the sport fishermen.

This report is based on data for 499 recaptures over a period of 3 years. For each recaptured fish we know the date and location of release and recovery and the method of recapture. Distances between points of release and recapture were measured as straight lines on U. S. Corps of Engineers Lake Survey charts.

The Western Basin of Lake Erie and its tributaries were divided into recovery areas to facilitate the analysis of the data (Figure

1). Recoveries from the six tagging areas were combined since walleyes released in all areas appeared to exhibit similar movements.

### DISTRIBUTION OF RECOVERIES

Tagged walleyes traveled primarily north toward the islands in the Western Basin during their first year of liberation, and in succeeding years moved progressively toward the extreme western end of the lake. Some walleyes were recaptured within 6 months in the Detroit River, Lake St. Clair, the St. Clair River, and southern Lake Huron. The percentage of fish recaptured in these waters north of Lake Erie increased annually. Movement eastward into the Central and Eastern Basins of the lake appeared negligible; only three fish were recovered east of Lorain, Ohio, during the 3-year study.[3]

#### *Recoveries in 1960*

Tagged yearling walleyes recaptured in 1960 numbered 330 (Table 1). Most of the 69 recoveries made in April and May 1960 (the same months in which the fish were tagged) were taken close to the tagging areas. Thirty-two of these fish were returned to the water after their tag numbers were recorded. The most distant recaptures were of two fish caught in the mouth of the Detroit River.

In June, July, and August, 56 marked fish were recovered. The walleyes began to disperse from the tagging area during these three months. The average distance traveled by the fish at this time was 20 miles. Fifty-two percent of the recaptures during the three months were taken in the so-called "Islands Area" (Recovery Area D, Figure 1). Three fish were caught west of Pelee Point, Ontario (Recovery Area H), and one walleye was recovered in the Detroit River. The first marked walleye known to have traveled an appreciable distance into the Central Basin of the lake was caught west of Cleveland.

The largest number of walleyes recovered in any limited period during the experiment was taken in September and October 1960. Of 174 tags returned, 105 were taken in the Islands Area. An increase in the movement of walleyes out of Lake Erie was indicated by the recapture of six marked fish at the mouth of the Detroit River, one in the Detroit River, one in Lake St. Clair, and two in the St. Clair River. One of the walleyes caught in Lake St. Clair was first caught at the outlet of the lake and released; after 2 months it was recaptured in the Middle Channel where the St. Clair River enters Lake St. Clair. Three fish were taken in the Toledo, Ohio–Monroe, Michigan, area (Recovery Areas F and G), and one walleye was caught in the Eastern Basin near Dunkirk, New York. Six fish were caught west of Pelee Point, Ontario (Recovery Area H). The remaining 49 recaptures were from scattered locations along the south shore of the Western Basin.

The movement of fish caught in November and December 1960 is difficult to interpret since most of the United States trap-net fishermen ceased operations in November. Of 31 recaptures, 27 were made in the Islands Area; two walleyes were caught at the western end of the lake and two more were recovered off Pelee Point, Ontario.

#### *Recoveries in 1961*

The marked walleyes caught during January–March 1961 were too few to give an accurate idea of the distribution of the tagged walleyes in Lake Erie at that time. Furthermore, Ohio commercial fishermen could not begin operations until March 15. Two fish were recovered in January in the Detroit River, and one was taken in Lake St. Clair. No tags were returned in February, but in the following month three fish were taken near the Islands Area, two in Sandusky Bay (Recovery Area B), and four between Toledo and Port Clinton, Ohio (Recovery Areas C, E, and F).

The 88 marked walleyes taken in April and May 1961 included 23 taken in La Plaissance Bay at the extreme western end of the lake (Recovery Area G), 10 in Lake St. Clair, and one each in the Detroit River and St. Clair River. In addition, 13 were recaptured in the Islands Area and 39 fish in scattered locations along the south shore of Lake Erie between Toledo and Vermilion, Ohio (Recovery Areas

[3] In 1960 and 1961, 12.1 percent and 22.4 percent, respectively, of the walleyes produced commercially in Lake Erie were taken east of a line from Lorain, Ohio, to Pelee Point, Ontario.

TABLE 1.—*Numbers and percentages of marked walleyes recovered at various localities in each of three years following tagging*

| Locality[1] | Year of recapture | | | | | | Total number | Percentage of total |
|---|---|---|---|---|---|---|---|---|
| | 1960 | | 1961 | | 1962 | | | |
| | Number | Percentage | Number | Percentage | Number | Percentage | | |
| Lake Erie | | | | | | | | |
| Area A | 30 | 9.1 | 8 | 5.3 | — | — | 38 | 7.6 |
| Area B | 48 | 14.5 | 12 | 8.0 | 3 | 15.8 | 63 | 12.6 |
| Area C | 25 | 7.6 | 8 | 5.3 | 1 | 5.3 | 34 | 6.8 |
| Area D | 178 | 53.9 | 41 | 27.3 | 4 | 21.1 | 223 | 44.7 |
| Area E | 18 | 5.5 | 9 | 6.0 | 1 | 5.3 | 28 | 5.6 |
| Area F | 2 | 0.6 | 13 | 18.7 | 3 | 15.8 | 18 | 3.6 |
| Area G | 2 | 0.6 | 24 | 16.0 | — | — | 26 | 5.2 |
| Area H | 11 | 3.3 | 1 | 0.7 | — | — | 12 | 2.4 |
| East of Lorain, Ohio | 2 | 0.6 | 1 | 0.7 | — | — | 3 | 0.6 |
| **Subtotals** | **316** | **95.7** | **117** | **88.0** | **12** | **63.3** | **445** | **89.1** |
| Detroit River | 10 | 3.0 | 9 | 6.0 | 2 | 10.5 | 21 | 4.2 |
| Lake St. Clair | 1 | 0.3 | 14 | 9.3 | 4 | 21.1 | 19 | 3.8 |
| St. Clair River | 2 | 0.6 | 9 | 6.0 | — | — | 11 | 2.2 |
| Lake Huron | | | | | | | | |
| Southern area | 1 | 0.3 | — | — | 1 | 5.3 | 2 | 0.4 |
| Saginaw Bay | — | — | 1 | 0.7 | — | — | 1 | 0.2 |
| **Subtotals** | **14** | **4.2** | **33** | **22.0** | **7** | **36.9** | **54** | **10.8** |
| **Totals** | **330** | **99.9** | **150** | **100.0** | **19** | **100.2** | **499** | **99.9** |

[1] See Figure 1 for locations of recovery areas.

A, B, C, E, and F), with the exception of one recovery west of Pelee Point, Ontario (Recovery Area H).

The 44 recoveries during June, July, August, and September 1961 included 21 from the waters around the Islands Area during a period of extremely heavy fishing west of Pelee Island. Sixteen walleyes had left Lake Erie and were caught at the following locations: six in the Detroit River; two in Lake St. Clair; seven in the St. Clair River; and one in Saginaw Bay, Lake Huron. Four fish were recovered between Sandusky and Vermilion, Ohio, and two in the western end of the lake. One fish was taken to the east near Erie, Pennsylvania.

No walleyes were recaptured in October or December, but in November four were caught near Pelee Island and two in Lake St. Clair.

### *Recoveries in 1962*

Only 19 marked fish were recaptured in 1962 (Table 1). Seven of these walleyes were taken in the Detroit River, Lake St. Clair, St. Clair River, and Lake Huron. Four fish were taken in the Islands Area, six were scattered along the south shore of the Western Basin, and two were caught west of Pelee Point.

### *Second recaptures*

Forty marked walleyes were recaptured and re-released during the study. Thirty-two of these fish were taken within 1 month after tagging near the tagging locality and re-released in the same area. Of these 32 fish three were later captured. One was taken during the latter part of May 1960 in the tagging area, one was caught in October 1960 after moving from Sandusky Bay to a point 12 miles west of Pelee Island, and one was recaptured in southern Lake Huron in April 1962. Of the remaining second releases, four were later captured a second time—three in the tagging area. The remaining marked walleye, tagged off South Bass Island and recaptured first at the outlet of Lake St. Clair in August 1960, was caught a second time, 7 months later, in the Middle Channel, one of the inlets of Lake St. Clair.

## SIGNIFICANCE OF MOVEMENTS

### *Movements between lakes*

Doan (1942) reported that of the 22 fish recovered from 1,248 walleyes tagged in the western basin of Lake Erie, only one had left the lake by means of the Detroit River. Studies by Ferguson (*op. cit.*) and Ferguson and Cummins (*op. cit.*) suggested that walleyes do move out of Lake Erie to a limited extent. In the present study, significant numbers of marked fish were recaptured in the Detroit River, Lake St. Clair, the St. Clair River, and

TABLE 2.—*Numbers and percentages of marked walleyes recovered at various distances from point of release in each of three years following tagging*

| Distance traveled (miles) | Year of recapture | | | | | | Total number | Percentage of total |
|---|---|---|---|---|---|---|---|---|
| | 1960 | | 1961 | | 1962 | | | |
| | Number | Percentage | Number | Percentage | Number | Percentage | | |
| 1 or less | 51 | 15.5 | 4 | 2.7 | 2 | 10.5 | 57 | 11.4 |
| 2– 5 | 17 | 5.2 | — | — | — | — | 17 | 3.4 |
| 6– 10 | 35 | 10.6 | 9 | 6.0 | 1 | 5.3 | 45 | 9.0 |
| 11– 30 | 193 | 58.5 | 74 | 49.3 | 5 | 26.4 | 272 | 54.4 |
| 31– 50 | 24 | 7.2 | 30 | 20.1 | 5 | 26.4 | 59 | 11.8 |
| 51– 70 | 5 | 1.5 | 9 | 6.0 | 1 | 5.3 | 15 | 3.0 |
| 71– 90 | 2 | 0.6 | 8 | 5.3 | 2 | 10.5 | 12 | 2.4 |
| 91–110 | — | — | 10 | 6.7 | 2 | 10.5 | 12 | 2.4 |
| 111–130 | 2 | 0.6 | 5 | 3.3 | — | — | 7 | 1.4 |
| 131–150 | — | — | — | — | 1 | 5.3 | 1 | 0.2 |
| 151–190 | 1 | 0.3 | — | — | — | — | 1 | 0.2 |
| 191–236 | — | — | 1 | 0.7 | — | — | 1 | 0.2 |
| Totals | 330 | 100.0 | 150 | 100.1 | 19 | 100.2 | 499 | 99.8 |
| Average distance | 18 | — | 39 | — | 45 | — | 25 | — |

Lake Huron. The percentage of the total annual recaptures made in waters north of Lake Erie increased each year. In 1960, only 3.9 percent of the 330 recaptured fish were taken in the Detroit River, Lake St. Clair, the St. Clair River, and Lake Huron. This figure increased to 22.0 percent in 1961 and to 36.9 percent in 1962. By the end of 1962, 53 walleyes (10.6 percent of the total recoveries) had been taken in these waters.

Fourteen of the 19 walleyes caught in Lake St. Clair were recovered near the mouth of the Thames River. This stream has a considerable run of spawning walleyes each spring (Ferguson, *op. cit.*). Nine of the fish tagged in 1960 were taken during the walleye spawning season in the river. Ferguson and Cummins (*op. cit.*) and Ferguson (*op. cit.*) found that immature walleyes tagged in Lake St. Clair and the Thames River do move down to Lake Erie as well as up to Lake Huron and have suggested that these two bodies of water serve as nursery areas for some of the walleyes in Lake Erie. If their view is correct, some of the walleyes marked by us that were taken near the mouth of the Thames River by commercial fishermen may have been returning to their "home" stream. This is physiologically possible because male walleyes in Lake Erie spawn at the age of 2 years and females at 3 years. By the end of 1961 the tagged walleyes had completed three growing seasons, and examination of the gonads of a small number of specimens showed that most were sexually mature.

*Distances traveled*

Most walleye tagging studies (Stoudt and Eddy, 1939; Eschmeyer, 1942; Herman, 1947; Eddy and Surber, 1947; Manges, 1950) have demonstrated that fish of this species sometimes travel great distances. Carbine and Applegate (1946) reported that tagged walleyes traveled downstream in the Muskegon River from the Muskegon River weir near Houghton Lake to the Big Rapids Dam, a distance of 130 miles. Eschmeyer (1950) stated that a walleye tagged below the Newaygo Dam on the Muskegon River was recaptured in Good Harbor Bay in Lake Michigan, 175 miles distant. Ferguson and Cummins (*op. cit.*) found that two walleyes tagged in Lake St. Clair had traveled at least 175 miles into Saginaw Bay, Lake Huron. Doan (1942) reported the recapture of a tagged walleye in the eastern end of Lake Erie, 200 miles from its point of release near South Bass Island. Of the 499 fish that we recovered in 3 years, 10 were taken over 110 miles from their points of release (Table 2). The most distant recovery was in Saginaw Bay, Lake Huron, 236 miles from the release point. Two other tagged walleyes were caught in southern Lake Huron, 129 and 146 miles from the tagging locality. Five fish recaptured in the St. Clair River had traveled from 113 to 128 miles. Two of the three walleyes that were taken east of Lorain, Ohio, had moved to the vicinity of Erie, Pennsylvania, and Dunkirk, New York—distances of 130 and 182 miles, respectively.

The average distance traveled increased from 18 miles in 1960 to 39 miles in 1961 and 45 miles in 1962. The mean distance traveled by all of the marked fish recaptured during the 3 years of our study was 25 miles.

Of the total of 499 marked fish recovered, 32.7 percent were taken in Canadian waters and 62.3 percent in United States waters. The percentages of recoveries by each type of gear were as follows: U. S. trap net—51.9 percent; U. S. sport fishery—9.4 percent; U. S. seine—3.4 percent; U. S. gill net—2.6 percent; Canadian gill net—25.7 percent; Canadian trap net—2.8 percent; Canadian pound net—2.2 percent; and Canadian sport fishery—2.0 percent.

## GROWTH OF TAGGED WALLEYES

The growth rate of tagged walleyes did not appear to differ significantly from that of unmarked fish of the same year class. Average total length of 68 tagged fish taken in small-meshed gill nets in Canadian waters in the late fall of 1960 was 14.4 inches, compared to 13.9 inches for a sample of 200 unmarked yearling walleyes taken in the same waters with the same gear and in the same season. Total length was recorded for only eight recaptured fish taken in the late fall of 1961. These walleyes had an average total length of 17.3 inches. Unmarked walleyes of the 1959 year class taken in commercial catches during the same period averaged 17.1 inches in length.

## ACKNOWLEDGMENTS

Harry Van Meter, Fred Notestine, and Paul Leidorf assisted in the field. Many Ohio commercial fishermen made fish available for tagging. R. G. Ferguson and Joseph Kippax of the Ontario Department of Lands and Forests and members of the Ohio Division of Wildlife cooperated by returning recovered tags and providing biological data. Vernon C. Applegate advised in the preparation of the manuscript.

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# SYNOPSIS OF BIOLOGICAL DATA ON ALBACORE
# Thunnus germo (Lacépède), 1800 (PACIFIC AND INDIAN OCEANS)

## Exposé synoptique sur la biologie du germon
## Thunnus germo (Lacépède), 1800 (Océans Pacifique et Indien)

## Sinopsis sobre la biología de la albacora
## Thunnus germo (Lacépède), 1800 (Oceanos Pacífico e Indico)

Prepared by
HOWARD O. YOSHIDA AND TAMIO OTSU
U. S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

FISHERIES DIVISION, BIOLOGY BRANCH
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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* As no information was available to the author, these items are not listed in the text.

# 1 IDENTITY

## 1.1 Taxonomy

### 1.1.1 Definition

Classification down to family after Schultz, et al 1960.

Phylum CHORDATA
Subphylum Craniata
Superclass Gnathostomata
Class Osteichthys
Subclass Teostomi
Superorder Teleosteica
Order Percomorphida
Suborder Scombrina
Family Scombridae
Genus Thunnus South 1845
Species Thunnus germo (Lacépède), 1880

### 1.1.2 Description

- Genus Thunnus South 1845

"Body moderately robust; snout pointed, not very long; mouth rather large; maxillary not concealed by preorbital; teeth in jaws small, those on vomer and palatines in villiform patches; gill rakers long, moderately slender; scales covering entire body, enlarged, and forming a corselet in region of pectorals; interval between dorsal fins slight; first dorsal with 12 to 15 rather slender spines, the fin high anteriorly; second dorsal and anal each followed by 8 or 9 finlets; ventral fins rather small, less than half length of head; pectoral short or long, with about 32 to 35 rays." (Hildebrand, 1946).

- Thunnus germo (Lacépède) 1800

"Body elongate, fusiform; caudal peduncle slender, keel on each side. Head conical; mouth terminal, moderate; gill rakers below angle of first gill arch, 19 to 21. Fins: dorsal (2), XIII or XIV - II, 13 or 14, interspace very short, spinous fin long, high anteriorly, finlets 7 or 8; anal, II, 12 or 13, origin below insertion of rayed dorsals, finlets, 7 or 8; pelvic I, 5, thoracic; pectoral very long, longer than head, reaching behind insertion of anal fin, sabre-shaped; caudal lunate. Lateral line: decurved anteriorly, nearly straight for greater part of length. Scales: cycloid, moderate, covering body; corselet small, indistinct. Color: metallic steely blue on dorsal surface and sides; silvery on ventral surface." (Clemens and Wilby, 1946). (Fig. 1).

The internal anatomy of the albacore has been studied in great detail by Godsil and Byers (1944) and Kishinouye (1923). Excerpts from these studies are presented below.

"The view of the viscera in situ is strikingly different from that of any other tuna investigated. The course of the intestine from right side to left across the abdominal cavity, the location of the spleen on the left side, and relatively conspicuous position of the gall-bladder serve to distinguish this tuna from any other.

"The center lobe [of the liver] is always the longest, and the outline of all lobes is quite irregular, due to extensive lobulation. The ventral surface of all lobes is always marked with characteristic radiating striations, and large conical vascular cones are invariably present on the dorsal face of each lobe. There are generally two moderate cones beneath the right lobe, one large one beneath the center lobe, and four or five small ones beneath the left lobe.

"In the albacore the straight intestine, in ventral view, appears anteriorly upon the right side of the fish, but in the anterior half of the abdominal cavity it crosses to the left side. Both anterior and posterior bend, and in consequence the fold of the intestine, are located on the left side of the abdominal cavity, and the descending portion of the intestine runs to the vent against the left wall of the body cavity.

"In shape and location the spleen of the albacore differs from that of the remaining tunas. This is the only species in which the spleen appears on the left side of the abdominal cavity.

"Due to its location, the gall-bladder is a conspicuous and distinctive character in the albacore. It follows closely the course of the straight intestine from its apparent origin anteriorly on the right side. Crossing with this to the left side of the fish it continues posteriorly beyond the posterior bend of the intestine. It lies on the median side of the intestine as a tubular, green structure and can rarely be overlooked. A short distance beyond the posterior bend of the intestine, the gall-bladder doubles anteriorly upon itself and, reaching the bend of the intestine, terminates here or occasionally again doubles back upon itself." (Godsil and Byers, 1944)

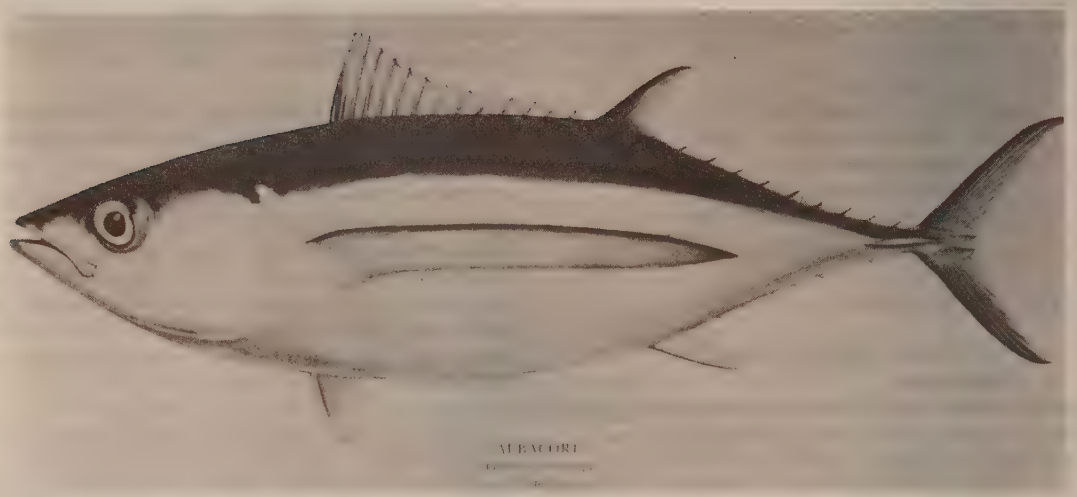

Fig. 1 Thunnus germo (Lacépède) (reproduced from Walford, 1937)

"Skull rather narrow. Vertebral column more or less slender. Height of the vertebrae nearly uniform. Parapophyses well developed. Parapophyses of the ninth vertebra are almost horizontal as in the preceding vertebrae; but in the tenth vertebra the haemal arch is formed and is turned forward leaving only a little space between the centrum and the arch. In each of the following precaudal vertebrae the haemal spine is formed, and it is remarkable that it is nearly uniformly elongated. These precaudal haemal spines are remarkably longer than in other tunnies. The head of the second and third ribs is very thick, and the distal portion of these ribs is broad, thin, and gradually narrow. The part between the head and the broad distal portion is very narrow to admit the passage of the cutaneous blood vessels." (Kishinouye, 1923)

## 1.2 Nomenclature

### 1.2.1 Valid scientific name(s)

Thunnus germo (Lacépède)

It should be mentioned here, without delving into the details, that the validity of this name has not been verified. Collette (MS)[1/] and Roedel and Fitch (MS)[2/] have discussed the problems concerned with the taxonomy and nomenclature of the tunas in some detail.

### 1.2.2 Synonyms

Collette (MS) has compiled a list of synonyms of the albacore. The names that have been applied to the albacore in the Pacific and Indian Oceans are listed below.

Scomber germo Lacépède 1800
Thynnus pacificus Cuvier in Cuvier and Valenciennes 1831
Thunnus pacificus South 1845
Orcynus pacificus Cooper 1863
Orcynus germo Lütken 1880
Germo alalunga Jordan and Everman 1896
Germo germo Jordan and Seale 1906
Thunnus alalunga Jordan, Tanaka and Snyder 1913
Thunnus germo Kishinouye 1923

### 1.2.3 Standard common names, vernacular names

The common and vernacular names listed in Table I were drawn primarily from the list compiled by Rosa (1950).

## 1.3 General variability

### 1.3.1 Subspecific fragmentation (races, varieties, hybrids) (see also section 1.3.2)

- Meristic counts

Meristic counts on albacore from various localities are presented in Table II.

- Varieties

Godsil (1948) compared albacore from California and Japan and noted that "the Japanese albacore are characterized by a relatively shorter head and caudal region and a longer abdominal or central trunk."

Kurogane and Hiyama (1959) compared albacore taken from several different localities. They found that the albacore from the Indian Ocean had larger heads and much posteriorly positioned fins than albacore from the northwest Pacific. Also, they concluded that albacore from the Indian Ocean and the southwest Pacific Ocean did not form a homogeneous population because of the rather great differences between them. However, the difference was not as great as that between the albacore in the Indian Ocean and the northwest Pacific. Therefore, they further concluded that there existed a possibility of intercourse between the populations in the Indian Ocean and the southwest Pacific Ocean.

1/ Collette, Bruce B., MS. A preliminary review of the tunas of the genus Thunnus. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

2/ Roedel, P.M. and J.E. Fitch, MS. Taxonomy and nomenclature of the Pacific tunas. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

Table I

Common and vernacular names

| Country | Standard common name | Vernacular name(s) |
|---|---|---|
| Australia | Albacore | |
| Canada | Albacore | Longfin albacore, Longfin tuna |
| Chile | Atun de aleta larga | Atun |
| Hawaii | Albacore | Longfin albacore, Ahipalaha |
| Japan | Binnaga | Bincho, Tomboshibi, Kantaro |
| Mexico | Albacora | |
| New Zealand | Longfin albacore | |
| Peru | Alalonga | |
| Philippines | Albacore | Albakora (Tagalog), Kiyawon (Bikol) |
| Union of South Africa | Albacore | Longfin albacore, Longfin tunny Longfin tuna |
| United States | Albacore | Longfin albacore, Longfin tuna, Albacora, Alilonghi, Germon, Abrego |

Table II

Meristic counts of albacore

| Locality | Gill Raker Counts: Upper limb | | | | | Lower limb | | | | | | | Upper and lower limbs combined | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 8 | 9 | 10 | 18 | 19 | 20 | 21 | 22 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| Japan | - | 3 | 5 | - | - | 1 | 5 | 2 | - | - | - | 1 | 1 | 5 | 1 | - | - |
| Hawaii | - | 1 | 2 | - | - | - | 3 | - | - | - | - | - | 1 | 2 | - | - | - |
| California | - | 2 | 8 | 1 | - | 1 | 7 | 3 | - | - | - | - | 2 | 6 | 3 | - | - |
| Indian Ocean | 1 | 12 | 25 | - | - | 7 | 20 | 10 | 1 | - | - | 5 | 9 | 15 | 8 | 1 | - |
| Northwest Pacific | 2 | 38 | 58 | 4 | 4 | 14 | 59 | 24 | 1 | 1 | 1 | 8 | 32 | 44 | 12 | 3 | 1 |
| Southwest Pacific | 5 | 52 | 66 | 4 | 1 | 23 | 71 | 29 | 3 | - | 2 | 14 | 41 | 45 | 23 | 2 | - |

| Locality | 1st dorsal fin | | 2nd dorsal fin | | Dorsal finlets | | 2nd dorsal fin plus dorsal finlets | | Anal fin | | Anal finlets | | Anal fin plus Anal finlets | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 13 | 14 | 15 | 16 | 7 | 8 | 22 | 23 | 14 | 15 | 7 | 8 | 21 | 22 |
| Japan | - | 9 | 2 | 5 | 6 | 3 | 1 | 6 | 2 | 7 | 8 | 1 | 1 | 8 |
| Hawaii | 1 | 2 | - | 3 | 3 | - | - | 3 | - | 3 | 3 | - | - | 3 |
| California | 3 | 8 | 3 | 7 | 8 | 3 | - | 10 | 1 | 10 | 10 | 1 | - | 11 |

| Locality | 1st dorsal spine | | | |
|---|---|---|---|---|
| | 12 | 13 | 14 | 15 |
| Indian Ocean | - | 39 | 84 | - |
| Northwest Pacific | 3 | 74 | 206 | 1 |
| Southwest Pacific | - | 53 | 127 | - |

Note: Japan, Hawaii, and California data from Godsil and Byers (1944); Indian Ocean, Northwest Pacific, and Southwest Pacific data from Kurogane and Hiyama (1959).

1.3.2 Genetic data (chromosome number, protein specificity)

Suzuki, Morio, and Mimoto (1959) discovered a blood group system designated Tg1 - Tg2 - O in the albacore. Sprague (MS)[3/] discovered another blood group system designated the G-system. Other systems that have been recognized in the albacore are the A-system and C-system (Sprague and Nakashima, MS).[4/]

The blood group characteristics have been utilized in studying the problem of subpopulations of albacore. Suzuki, et al. (1959) compared the blood group frequency of albacore from the North Pacific and the Indian Oceans and found striking differences between the two. Marr and Sprague (MS)[5/] subjected the data from Suzuki, et al. to another analysis and concluded that the Pacific Ocean samples were drawn from a single interbreeding population, but that the Indian Ocean samples were drawn from a mixture of two or more interbreeding populations.

Sprague (MS, see footnote 3) noted that the difference in the relative proportions of phenotypes of C-positive albacore from Samoa and North America was highly significant and concluded that the albacore from the two areas are representative of genetically isolated stocks.

3/ Sprague, Lucian M., MS. Blood group studies of albacore (Germo alalunga) tuna from the Pacific Ocean. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

4/ Sprague, Lucian M. and Leslie I. Nakashima, MS. Studies on the erythrocyte antigens of the skipjack tuna (Katsuwonus pelamis). Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

5/ Marr, John C. and Lucian M. Sprague, MS. The use of blood group characteristics in studying subpopulations of fishes. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

## 2 DISTRIBUTION

### 2.1 Delimitation of the total area of distribution and ecological characterization of this area

The distribution of albacore in the Pacific and Indian Oceans is shown in Fig. 2, which was adapted from Fig. 11 of Brock (1959a). It can be seen from this chart that albacore is quite cosmopolitan in distribution. On the eastern side of the North Pacific, albacore has been recorded from Baja California to the Gulf of Alaska. In the western North Pacific albacore is distributed from the Equator to approximately 45° N latitude. Centered approximately along 35° N latitude, albacore has a continuous distribution across the North Pacific Ocean.

In the South Pacific, albacore has been recorded from the Equator to 45° S latitude and from the east coast of Australia to the coast of Chile. However, the occurrence of albacore from about 135° W longitude to the coast of Chile is quite spotty.

The range of distribution of albacore in the Indian Ocean is from approximately 10° N to 30° S latitude and from Australia to the east coast of Africa.

The major oceanographic features of these areas were described in a general way by Brock (1959a). Figs. 3, 4, 5, 6, and 7 were adapted from Brock and show the ocean current systems, summer average surface temperature and depth of thermocline, winter average surface temperature and depth of thermocline, respectively.

### 2.2 Differential distribution

#### 2.2.1 Areas occupied by eggs, larvae and other junior stages; annual variations in these patterns, and seasonal variations for stages persisting over two or more seasons. Areas occupied by adult stages: seasonal and annual variations of these

- Larval stages

There is very little information on the distribution of larval albacore. Table III lists some records of the occurrence of larval albacore, based on the tentative identification of Matsumoto (MS). 6/

Table III

Occurrence of larval albacore 1/

| Date | Position | | No. of Albacore larvae |
|---|---|---|---|
| May 1929 | 20°04' N | 123°59' E | 1 |
| May 1929 | 25°30' N | 125°28' E | 259 |
| June 1929 | 14°37' N | 119°52' E | 1 |
| July 1929 | 00°50' S | 134°15' E | 1 |
| September 1929 | 01°29' S | 100°07' E | 2 |
| October 1929 | 02°57' S | 99°36' E | 1 |
| November 1929 | 04°20' N | 98°47' E | 1 |
| January 1952 | 01°54' N | 155°03' W | 1 |
| May 1952 | 01°57' N | 140°03' W | 1 |
| May 1952 | 03°09' N | 139°53' W | 1 |
| November 1957 | 09°13' S | 141°35' W | 1 |
| February 1958 | 02°10' S | 144°08' W | 1 |
| February 1958 | 07°12' S | 142°10' W | 4 |
| March 1958 | 06°20' S | 139°39' W | 1 |
| May 1958 | 09°12' S | 143°08' W | 1 |
| May 1958 | 09°14' S | 142°20' W | 5 |
| July 1960 | 09°05' N | 168°20' E | 1 |

1/ Data from files of U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.

6/ Matsumoto, Walter M., MS. Identification of larvae of four species of tuna from the Indo-Pacific Region. I. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

Fig. 2 Distribution of albacore in the Pacific and Indian Oceans (Brock, 1959a)

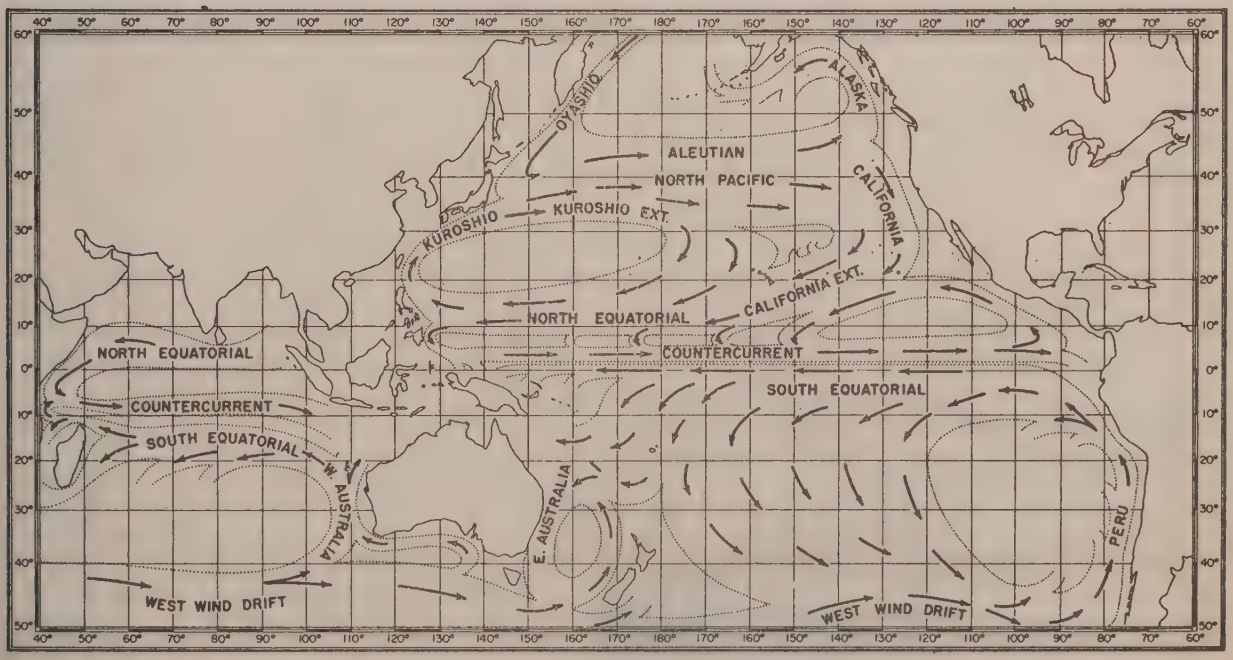


Fig. 3 Ocean current systems (Brock, 1959a)

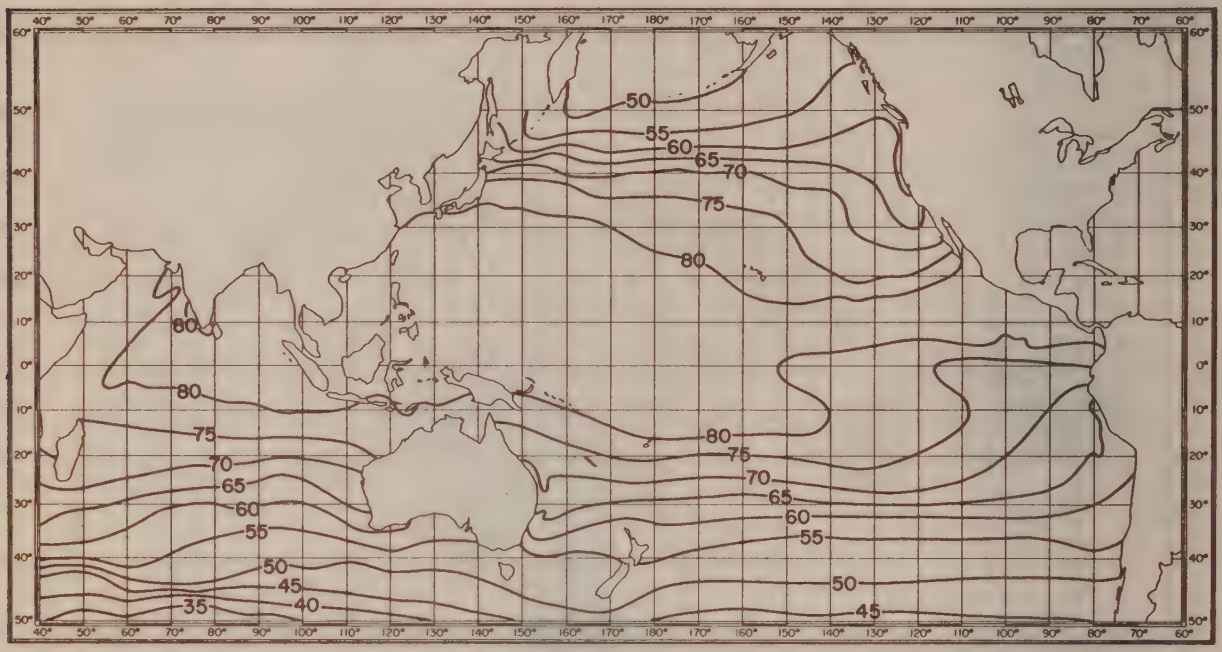


Fig. 4 Summer (August) average surface temperature (°F) (Brock, 1959a)

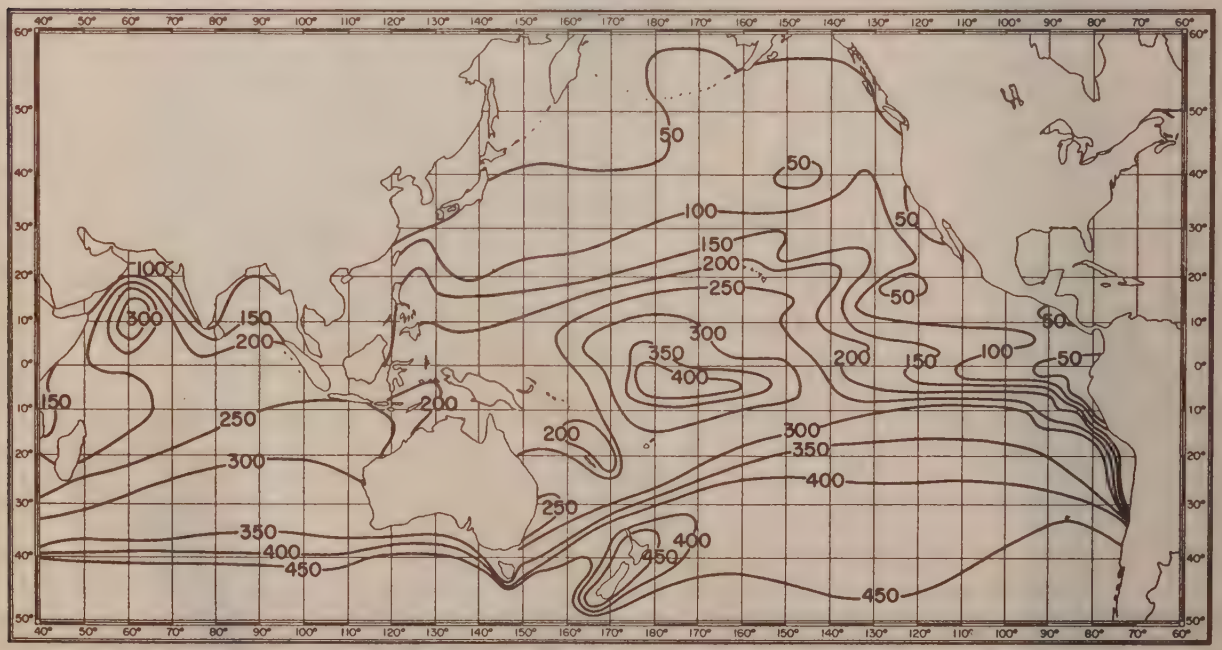


Fig. 5 Summer (August) depth of thermocline (feet) (Brock, 1959a)

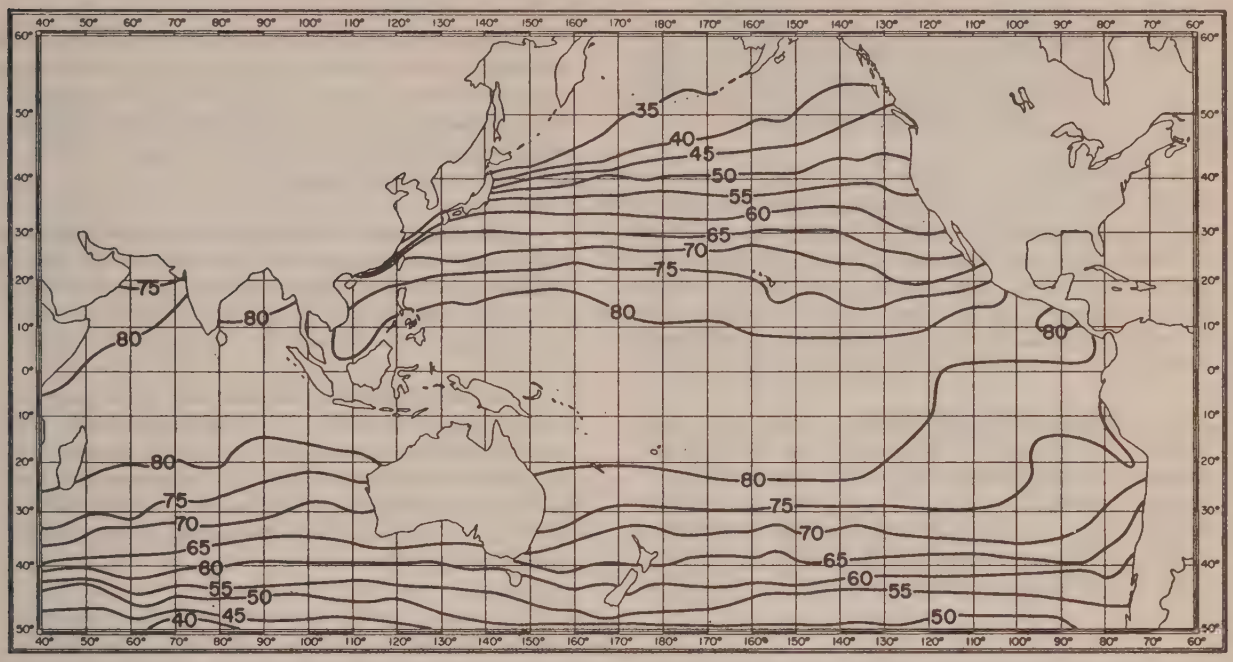


Fig. 6 Winter (February) average surface temperature (°F) (Brock, 1959a)

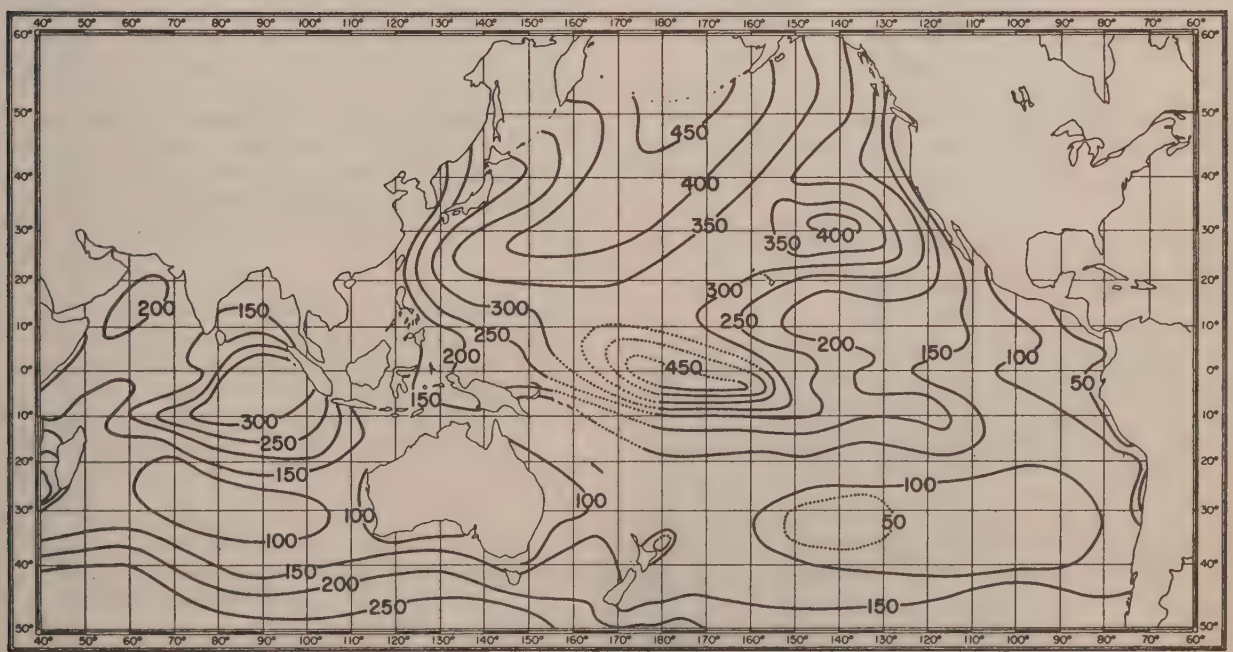


Fig. 7 Winter (February) depth of thermocline (feet) (Brock, 1959a)

2.3 Behavioristic and ecological determinants of the general limits of distribution and of the variations of these limits and of differential distribution

Radovich (1961) states, "It appears that Pacific albacore distribution along the North American coast is influenced by the environment, of which temperature is a strong indicator if not a primary factor in itself." According to Radovich, about 65 percent of the albacore caught by the California fishery from 1954 through 1956 were from water with surface temperatures between 60° - 64° F.

Clemens (1961) indicates that the movement of albacore along the west coast of the United States is regulated primarily by sea-surface temperatures between 58° - 68° F. According to Clemens, the area where the albacore moves into the fishing grounds shifts north and south with warming and cooling sea-surface temperatures.

In the area bounded by 160° W and the 180th meridian in the North Pacific, McGary, Graham, and Otsu (1960) showed that, during the winter, the latitudinal limits of the distribution of albacore were almost coincident with the southern boundary of the Transition Zone.

The Japanese believe that the devlopment of the surface summer albacore fishery off the coast of Japan is controlled by the way in which the seasonal warming of the area by the Kuroshio progresses (Van Campen, 1960).

In the western South Pacific, Yamanaka (1956) suggests that a "discontinuity layer with considerable convergence which is found extending from east to west in the neighborhood of latitude 10° S" plays an important part as a northern limit in the distribution of the South Pacific albacore.

## 3 BIONOMICS AND LIFE HISTORY

### 3.1 Reproduction

#### 3.1.1 Sexuality (hermaphroditism, heterosexuality, intersexuality)

The albacore is heterosexual. There are no external characters known to distinguish between the males and females. A case of hermaphroditism was cited by Legand (MS)[7/] in an albacore taken in waters off southwestern New Caledonia, but details were not given.

#### 3.1.2 Maturity (age and size)

It was first reported by Ueyanagi (1955) and later supported by the findings of Otsu and Uchida (1959a) that female albacore attain sexual maturity and thus may first spawn at about 90 cm in length. The smallest mature fish found in samples collected from the western Pacific (Ueyanagi, 1957) was 87 cm long, and the smallest from the central equatorial Pacific measured 89.1 cm (Otsu and Uchida, 1959a). Otsu and Hansen (1961) reported in their study of the central South Pacific albacore that some fish are already mature at 86 cm.

As for the males, Ueyanagi (1957) judged from their general appearance and oozing of milt that testes weighing more than 150 grams were probably ripe. From this, he postulated that the smallest mature fish measured 97 cm. Following the same criteria, Otsu and Hansen (1961) found that some male albacore are probably mature when they attain a length of about 90 cm. However, lacking more objective means of determining maturity of the males, it cannot be said with certainty that this is the size at which male albacore are first capable of spawning.

The age at maturity has not been satisfactorily determined for the albacore. Suda (1958) has postulated that spawning albacore are age-VI and older. Otsu and Uchida (MS)[8/] hypothesized that the 6-year-olds (94 cm.) and older age groups move south from the Japanese winter longline fishery into sub-tropical waters to form the reproductive unit of the North Pacific population.

#### 3.1.3 Mating (monogamous, polygamous, promiscuous)

No records of observations on spawning fish are available. However, imminently spawning albacore more than likely occur in aggregations and male and female fish probably release their sex products indiscriminately without specifically selecting any particular partner or partners.

#### 3.1.4 Fertilization (internal, external)

External. The eggs of the female and the milt of the male are discharged into the water, where the eggs are fertilized. The eggs and larvae are believed to occur in surface layers.

#### 3.1.5 Fecundity

Estimates of fecundity were based on the assumption that all the eggs comprising the most advanced group within an ovary were released in a single spawning (Ueyanagi, 1955 and 1957, and Otsu and Uchida, 1959a). These estimates ranged between 0.8 and 2.6 million eggs.

- Relation of gonad size and egg number to body size and to age

Otsu and Uchida (1959a) noted only a slight tendency for larger albacore to have more eggs per spawning.

#### 3.1.6 Spawning

- Spawning seasons (beginning, end, peak)

The spawning season of albacore has not been defined in detail. However, on the basis of seasonal changes in gonad maturity, Ueyanagi (1957) inferred that spawning in the western North Pacific occurs in subtropical

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7/ Legand, Michel, MS. Taille, repartition sexuelle, cycle annuel de L'Albacore dans L'ouest de la Nouvelle-Caledonie. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

8/ Otsu, Tamio and Richard N. Uchida, MS. A model of the migration of albacore in the North Pacific Ocean. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

waters during the summer months with June and July at its peak. Otsu and Uchida (1959a) also found evidence of spawning through examination of gonads of albacore taken in Hawaiian waters during the summer. The most highly developed ovaries were collected during June and July. From these results, it is believed that albacore spawning in the North Pacific occurs largely during the summer months in areas under the influence of the North Equatorial Current, and that the spawning grounds may be over a broad area extending to as far east as the Hawaiian Islands. The determination of the exact spawning period will have to await future field work which will involve the study of the seasonal distribution of larval albacore.

In the South Pacific, Otsu and Hansen (1961) found that the seasonal progression in gonad development peaked during December. The gradual increase in the proportion of late developing ovaries in the monthly samples from the low point in May to a peak in December, with a gradual decrease thereafter, suggested that spawning must take place during the southern summer months. Depending upon the rate of ova development, albacore may be spawning during only a portion of that period, and that portion may be towards the end, perhaps between January and March, when the percentage of late developing ovaries is decreasing. At any rate, the spawning season in the South Pacific is six months out of phase with that in the North Pacific. The spawning grounds appear to cover a broad area between the Equator and 20° S latitude. East-west differences in spawning activity were not discernible within the extent of the area sampled (130° W - 160° E ).

Ishii and Inoue (1956) reported on results of examination of ovaries of albacore taken in the Coral Sea (17° S - 20° S, 152° E - 153° E ) in January 1954. The authors postulated that the Coral Sea and the adjacent New Caledonia areas are spawning areas for the albacore. More recently Legand (MS) studied the seasonal trend of the ovary volume to body length relationship of albacore taken in waters within 200 miles of the southwest coast of New Caledonia (21° 30' S - 24° S) and reported that albacore spawning probably occurs in the summer (December-January).

In the Indian Ocean, Ueyanagi (1955) reported on highly developed ovaries obtained from albacore taken from waters south of Sunda Islands in February 1953. He concluded that, "The season and area of spawning have never been known concerning the albacore distributed in the Indian Ocean. It is now clear from the above findings that the spawning of this fish takes place in February at least in part."

- Number of spawnings per year (frequency)

Very little study has been conducted on the frequency of spawning in the albacore. The frequency distributions of egg diameters in albacore ovaries show clearly two or more modes which, depending on the growth rate of the egg, may represent eggs that will be spawned in a single season or in succeeding seasons. Otsu and Uchida (1959a) postulated from the presence of egg remnants in late developing ovaries that this species may undergo multiple spawning. The presence of egg remnants together with a group of eggs approaching ripeness suggested that albacore may spawn at least twice during a single spawning season. Further evidence along this line was obtained from the fact that remnants were absent in large, sexually inactive adults taken during late winter in the North Pacific, a suggestion that remnants are not carried over from one year to the next. However, in the absence of any knowledge regarding the rate of resorption of the unspawned eggs, no definite conclusions can be drawn.

- Induction of spawning, artificial fertilization

No instance of successful artificial fertilization in albacore has been recorded. Among the tunas, however, Kikawa (1953) and Kume (MS),[9/] both of the Nankai Regional Fisheries Experimental Station in Kochi, Japan, were able to artificially fertilize bigeye tuna eggs. In the latter experiment, conducted in 1961, the eggs were successfully hatched but the larvae soon succumbed to mortality.

9/ Kume, Susumu, MS. A note on the artificial fertilization of bigeye tuna, Parathunnus mebachi (Kishinouye). Nankai Regional Fisheries Laboratory, Kochi, Japan.

These experiments point out the possibility of artificial fertilization in albacore.

3.1.7 Spawning grounds

- Coastal (surface, vegetation, shore, shoal, sand, shelter); bottom

Albacore spawning is believed to take place in oceanic rather than coastal waters.

- Oceanic (surface, bottom)

As in other tunas, the albacore spawns in oceanic waters. The best information available indicates that spawning takes place in tropical and subtropical waters of both the Pacific and Indian Oceans. There is no evidence of temperate water spawning.

3.1.8 Egg: Structure, size, hatching type, parasites and predators

The most highly developed ovarian eggs recorded from the Pacific and Indian Oceans were found in albacore taken in waters around the Hawaiian Islands and Sunda Islands, respectively. These ovaries, although very highly developed, were not fully ripe. They contained eggs which measured about 0.8 mm in average diameter and the largest measured about 1 mm (Ueyanagi, 1955; Otsu and Uchida, 1959a). Ripe albacore eggs are therefore about 1 mm in diameter.

The immature oocytes under about 0.2 mm in diameter, which cannot be seen with the naked eye, are polygonal, colorless, and transparent, and fixed specimens stain deeply with hematoxylin. These oocytes, also referred to as "primitive eggs," are found in ovaries in all stages of development. In early development, the eggs increase in size and become semi-opaque from deposition of yolk granules. The maximum diameter of eggs in this stage is about 0.4 mm. With further development, the eggs become completely opaque from the heavy accumulation of yolk granules and the diameter now ranges from 0.4 to about 0.8 mm. Distinct changes occur in the eggs as they approach ripeness. They lose their opacity and become semi-transparent; the nucleus cannot be detected at this stage, and a conspicuous golden-yellow oil globule appears.

There are no records of capture of albacore with "running ripe" ovaries in the Pacific and Indian Oceans. Furthermore, it is not possible at present to satisfactorily distinguish between the pelagic eggs of the several species of tunas. In the Mediterranean Sea, Sanzo (1933) described the pelagic eggs of Orcynus germo Lütken [=? Thunnus alalunga (Bonnaterre)] taken in plankton net hauls in the Strait of Messina. He found the eggs, between 0.84 and 0.94 mm in diameter, to be buoyant, spherical, and highly transparent. The oil globule, which was always single, measured around 0.24 mm. Matsumoto (MS) in discussing Sanzo's description of the larvae which were successfully hatched from these eggs, cautioned that although the plankton collections were made during specific migratory runs of the species through the Strait, there was no definite assurance that the eggs of one species were collected exclusive of the other species which are also known to spawn during the same period.

No information is available on the hatching type, parasitic infection, and predation on albacore eggs.

3.2 Larval history

3.2.1 Account of embryonic and juvenile life (prelarva, larva, postlarva, juvenile)

No information on the embryonic (prelarva) stages of albacore is available from the Pacific and Indian Oceans. Sanzo (1933) reported on the ova and early larval stages of Orcynus germo (Lütken) [=? Thunnus alalunga (Bonnaterre)] from the Mediterranean Sea. Sanzo collected the fertilized ova in the Strait of Messina and was able to hatch the ova, and to rear the larvae up to seven days in his laboratory. As mentioned in section 3.1.8, however, there is some question whether Sanzo really reported on the ova and early larval stages of albacore or another species.

Recently Matsumoto (MS) was able to make tentative identification of larval albacore from among the larval tunas collected on the "Dana" expedition during 1928-30 (Fig. 8). According to Matsumoto, the larvae of albacore differ from those of yellowfin (Neothunnus macropterus) in having two chromatophores along the ventral edge of the body on the 28th and 33rd myotomes. Furthermore, the distinctive character which sets the albacore apart from bigeye (Parathunnus sibi) and yellowfin is the single chromatophore on the dorsal edge of the trunk.

- Feeding

Sanzo (1933) reported that between the second and third day after hatching the larvae began pecking on the bottom of the rearing jar.

- Rates of: development and survival

The earliest stage of the developing zygote that Sanzo was able to obtain was the stage of the closure of the blastopore. According to Sanzo, at this stage, the embryo extends halfway around the full circumference of the egg; the cephalic region is rather large; the secondary otic vesicles are formed, the otocysts, and about 10 muscle segments are present. After about 7 or 8 hours, the embryo has the tail developed to a greater length, turned upward and forward over the anterior surface of the oil globule, and about 40 segments can be counted. The embryonic development takes place in two days.

The development of the larva immediately after hatching is summarized in Table IV.

- Periods of: development and survival

(See section on rates of: development and survival).

- Parental care

Although no direct observations have been made, the young are most likely left to fend for themselves.

- Parasites and predators

Kishinouye (1923) states, "I found a young germon about 30 cm in length in the stomach of a large germon, caught on January 20th, 1917 near the Ogasawara Islands, and other small ones from a yellow-finned tunny and a spear fish caught on February 27th of the same year."

Table IV

The development of the larvae immediately after hatching
(adapted from Sanzo, 1933)

| Time after hatching | Development |
|---|---|
| 1st hour | The mouth opening is not yet formed; all signs of the branchial skeleton and the pectoral fins are lacking; the primordial fin fold is rather low anteriorly on the back; the eyes are without pigment; 10 specimens averaged 2.60 mm in length. |
| On the day after hatching | The primordial dorsal fin has become quite high anteriorly and extends to opposite the otic region; the mouth is not yet open; the heart has already rotated from its embryonic position; very small pectorals have made their appearance; one specimen at this stage measured 2.96 mm. |
| At the end of the first day | The stomodeum is in process of formation; the pectorals are slightly enlarged; specimens measured from 3.20 - 3.50 mm in length. |
| On the 2nd day | The mouth opening is formed; Meckel's cartilage is present; the hyoid and branchial apparatus are differentiated; the eye is rounded and has incipient pigmentation. |
| 2 to 3 days | The eyes are completely pigmentated. |
| On the 5th day | Primordial fins greatly developed; two large olfactory pits on snout; the eyes are large and slightly subrotund; posterior to them are two large otocysts with the semicircular canals differentiated. |
| After the 5th day | The larvae begin to reduce in length. |
| On the 7th day | The primordial fin is reduced; one specimen measured 3.20 mm; a toothlet present on upper jaw. |

Table V

Some records of predation on juvenile albacore
(Yabe, et al., 1958)

| Albacore body length | Date | Locality | Predator |
|---|---|---|---|
| 188 mm. | 5-15-49 | 18°38' N., 151°26' E. | Black marlin |
| 124 mm. | 6-11-52 | 20°57' N., 149°36' E. | Black marlin |
| ca. 170 mm. | 2-1-55 | 18°44' S., 176°54' E. | Yellowfin |
| ca. 170 mm. | 2-2-55 | 18°58' S., 176°27' E. | Yellowfin |
| 234 mm. | 12-6-56 | 20°50' S., 155°30' E. | Striped marlin |
| 258 mm. | 3-20-57 | 25°13' S., 99°43' E. | Shortnosed spearfish |

Table V lists other occasions of predation on juvenile albacore as reported by Yabe, Ueyanagi, Kikawa, and Watanabe (1958).

3.3 Adult history

3.3.1 Longevity

Uchida and Otsu (MS)[10/] indicate that there are about 10 age groups composing the Japanese winter longline fishery, of which the oldest group is 10 years old. The albacore that are caught in the Hawaiian Islands grow to a greater size (see Fig. 19). Uchida and Otsu did not attempt any age analysis of Hawaiian albacore "because of inaccuracies which may result from possible differential growth between the sexes in such large fish."

3.3.2 Hardiness

The fact that albacore survive after experiencing the handling involved in tagging and then go on to make trans-Pacific migrations may indicate that they are quite hardy.

Clemens (1961) says, "After having tagged several tons of albacore, yellowfin tuna, and skipjack, and a few bluefin and bigeye tuna, I believe that albacore are the hardiest of the five followed by bluefin, bigeye, yellowfin, and skipjack."

3.3.3 Competitors

Iversen (MS)[11/] reported that, "the similarities in diet between both the albacore and the yellowfin and albacore and the bigeye in the same specific location, as well as in the same general area, are evidence that there is some competition between the albacore and the other two species of tuna."

In the area near New Caledonia, Legand and Wauthy (MS)[12/] noted that "albacore and Alepisaurus compete in many ways for food"

3.3.4 Predators

Kishinouye (1923) made some general remarks on the enemies of scombroid fishes. He says, "The gigantic species of the scombroid fishes have few enemies. Their most dreaded enemies are dolphins, especially the killer. Killers often await the passage of large schools of tunnies in a strait, such as Tsugaru Strait, and attack them furiously."

Bennett (1840), in speaking of albacore, says, "It is, probably, as a protection from their chief enemy, the sword-fish, that they seek society of a ship. I am not aware that the shark is also their enemy; but they seemed to have an instinctive dread of this large fish, when it approached the ship, would follow it in

10/ Uchida, Richard N. and Tamio Otsu, MS. Analysis of sizes of albacore occurring in various Pacific fisheries - a preliminary report. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

11/ Iversen, Robert T.B., MS. Food of albacore tuna, Thunnus germo (Lacépède) in the central and northeastern Pacific. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August, 1961.

12/ Legand, M. and B. Wauthy, MS. Importance presumée d'Alepisaurus sp. dans le cycle biologique des thons de longue-ligne au large de la Nouvelle-Calédonie. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August, 1961.

shoals, and annoy it in the same manner as the smaller birds may be seen to annoy those of a larger and predaceous kind, as the hawk or owl." However, as mentioned in section 3.3.6 there is some doubt whether Bennett was really reporting on albacore.

Tunas, including albacore, caught by longlines are often damaged by sharks. It is not known whether sharks normally prey on tunas. Strasburg (1957) presents some lines of evidence to indicate that sharks may swim fast enough to catch free-swimming tuna. He says, "For one thing both species of sharks (silky and whitetip) are occasionally caught on trolling lines at vessel speeds of 6 to 8 knots, and for another, one bigeye tuna captured alive bore a pair of large U-shaped scars suspiciously resembling shark jaws in shape."

### 3.3.5 Parasites and diseases

Table VI lists records of infestation of albacore by various parasites in the Pacific Ocean.

### 3.3.6 Greatest size

The International Game Fish Association (1960) lists the world record for albacore, which was caught in the Atlantic Ocean, as 69 lbs. In the Pacific Ocean, it lists an albacore weighing 66 lbs. 4 oz as the largest caught by a sport fisherman. According to a table of length-weight relation, albacore weighing 66-69 lbs would be approximately 115-118 cm in length. Albacore of this size are commonly caught by longlines around Hawaii (see Fig. 15). Apparently, the albacore occurring around Hawaii are the largest in the Pacific Ocean, and the largest specimen recorded is the one reported by Otsu and Uchida (1959a), which weighed 93 lbs and measured 128 cm in length.

Bennett (1840) made some observations on the size of albacore. He noted that, "The average length of the examples we captured from the ship was four feet; though some others, which we saw on the coasts of the Polynesian Islands, measured nearly six feet." However, it is rather dubious that Bennett really saw albacore "nearly six feet," (or 189 cm). It is doubtful that albacore ever grow to anywhere near this size.

## 3.4 Nutrition and growth

### 3.4.1 Feeding (time, place, manner, season)

Iversen (MS) indicated that troll-caught albacore in the temperate North Pacific feed

Table VI

Parasites of albacore

| Parasite | Location of infestation | Reference |
|---|---|---|
| Elythrophora brachyptera | Inner surface of operculum | Yamaguti (1936) |
| Hirudinella spinulosa | Stomach | Yamaguti (1938) |
| Didymocystis alalongae | Gill arch | " " |
| Didymocystis opercularis | Operculum | " " |
| Platocystis alalongae | On skin | " " |
| Melanematobothrium guernei | In sub-maxillary muscle | " " |
| Anisakis sp. | ------ | Yamaguti (1941) |
| Contracaecum legendrei | Stomach | " " |

throughout the day. He also presented some evidence to indicate that albacore are able to feed at night. Iversen found, however, that albacore caught during hours of darkness by gillnets had smaller stomach volumes. He suggests that this is due to less successful foraging by albacore at night.

### 3.4.2 Food (type, volume)

In a study of albacore food in the South China Sea, Kanamura and Yazaki (1940) found squid, octopus, stomatopods, barracuda, "hairtail," "flatheads," ginkagami (Mene maculata), and "sardine" (Bathylagus nakazewai) in the stomachs of albacore.

Powell (1950) noted that small rockcod constituted the bulk of the food of albacore taken in the northeastern Pacific with squid, saury, small blackcod, and lantern fish present in varying amounts.

McHugh (1952) studied the food habits of troll-caught albacore off California and Baja California, and reported that, "By far the most important item was the Pacific saury (Cololabis saira), which constituted almost 50 percent of the total food volume. Next in order of importance were squids (12 percent); Pleuroncodes planipes, the pelagic decapod of southern waters (11 percent); euphausiids (7 percent); and the northern anchovy, Engraulis mordax mordax (4 percent)."

Barracuda, a species of "sand borer," and Ostracion diaphanus (=Lactoria diaphanus) were found in stomachs of albacore caught by longlines in waters around the Bonin Islands (Yabuta, 1953). However, Yabuta noted that albacore fed mostly on crustaceans and small cephalopods.

In the western Indian Ocean, Koga (1958a) found that the following were found in 10 percent or more of the albacore stomachs examined Triacanthidae, Plagyodontidae (= Alepisauridae) Carangidae, and Acinaceidae (=Gempylidae). Among the crustacea, isopods, decapods, and stomatopods occurred in 10 percent or more of the stomachs. Koga (1958b) also examined stomachs of albacore from the equatorial South Pacific and found that the following were present in 10 percent or more of the stomachs: Plagyodontidae, Triacanthidae, Acinaceidae, Ostraciidae, and Menidae. Squid were present in 50 percent, decapod crustaceans in 15 percent, and octopods in 10 percent of the stomachs.

Iversen (MS) examined the stomachs of 544 albacore captured by longlining, trolling and gill net fishing in the central and northeastern Pacific. He found that there were differences in the average volume and the composition of the foodstuffs in stomachs of albacore caught by different fishing methods (Table VII and Fig. 9).

Table VII

Average stomach volumes of 348 albacore, according to method of capture (Iversen, MS)

| Method of capture | Number of stomachs | Average volume (cc) per stomach |
|---|---|---|
| Longline | 182 | 26.7 |
| Gill net | 87 | 9.8 |
| Troll | 79 | 15.1 |

### 3.4.3 Relative and absolute growth patterns and rates

Studies on the age and growth of albacore in the Pacific Ocean have been made by Uno (1936a; 1936b), Aikawa and Kato (1938), and Partlo (1955), based on the vertebral method.

Suda (1954) studied the size composition of albacore taken in the Japanese winter longline season and found modes at 57 cm, 67 cm, 78 cm, 89 cm, 100 cm, and 111 cm. The spacing of the intervals was uniformly 10 or 11 cm, thus representing a straight-line growth if these length groups are assumed to be age classes. Suda concluded that these length groups may be considered as age groups if they are handled as five groups consisting of ages I to IV and an advanced age group which includes the last two modal groups.

Nose, Kawatsu, and Hiyama (1957) made a study of age and growth of albacore based on the scale method. They found that the lengths of albacore at the time of ring formation were as follows: $l_1$=38 cm, $l_2$=49 cm, $l_3$=59 cm, $l_4$= 68 cm, $l_5$= 78 cm, $l_6$= 86 cm, $l_7$= 96 cm, and $l_8$= 105 cm.

Otsu (1960) reported on a study of age and growth of albacore based on data obtained from tagging experiments. The growth rates derived by Otsu are presented in Table VIII and Fig. 10. Otsu (1960) also discussed the results obtained

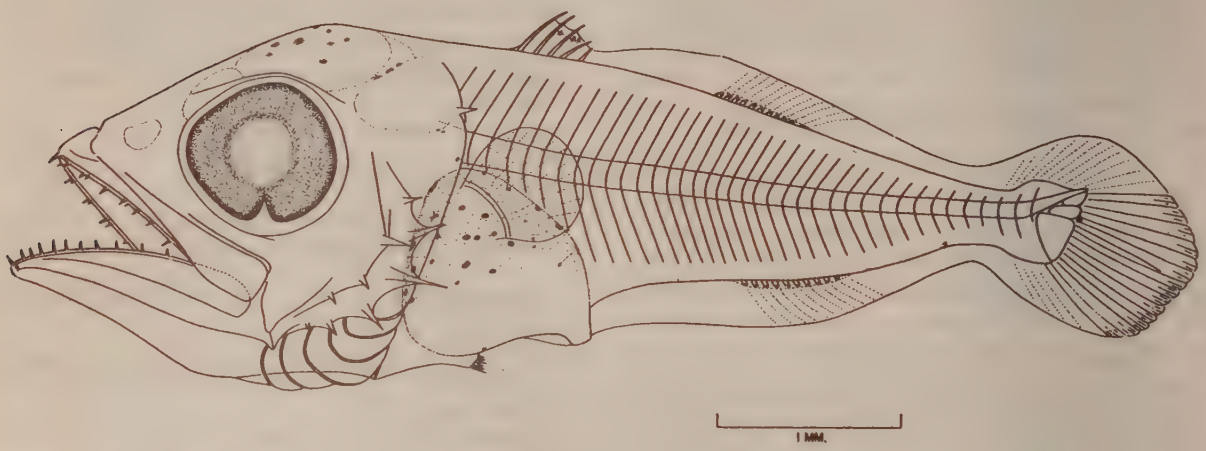


Fig. 8 Thunnus germo, 6.47 mm (reproduced from Matsumoto, MS)

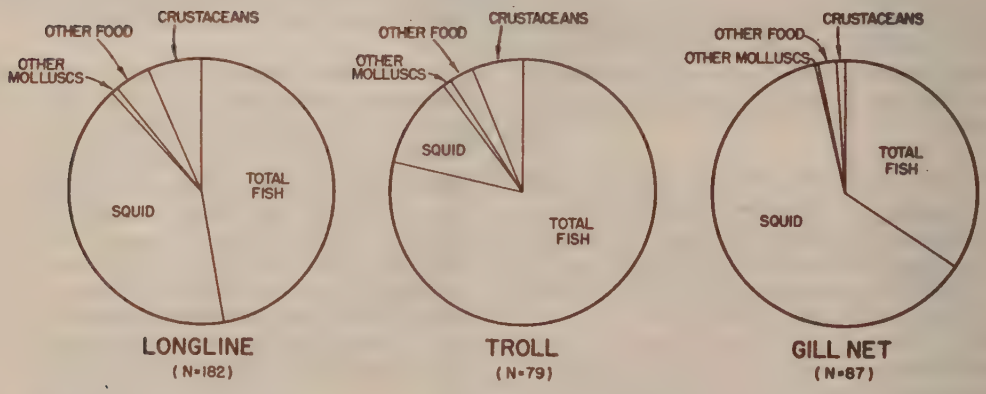


Fig. 9 Comparative importance, by volume, of major food elements found in 348 albacore stomachs (Iversen, MS)

by the earlier workers and noted that all the curves were linear, with the possible exception of Uno's (1936b) (Fig. 11), while the curves he derived were curvilinear. Although the several growth rates did not differ markedly in magnitude, Otsu points out that the linearity of the curves obtained by the earlier workers suggests that the vertebral method of aging albacore is not valid.

Table VIII

Growth rates of albacore derived by fitting tag recovery data to growth curves by the methods of Walford and Riffenburgh (Otsu, 1960)

| AGE* (years) | LENGTH (cm) | |
|---|---|---|
| | Walford | Riffenburgh |
| 1 | --- | 7.5 |
| 2 | --- | 17.3 |
| 3 | 26.3 | 31.5 |
| 4 | 46.8 | 46.5 |
| 5 | 62.7 | 62.5 |
| 6 | 75.1 | 75.0 |
| 7 | 84.8 | 86.0 |
| 8 | 92.3 | 94.5 |
| 9 | 98.2 | 101.0 |
| 10 | 102.7 | 106.0 |

* The ages given are based on an arbitrarily selected origin and are therefore tentative.

More recently, Clemens (1961) and Bell (1962) made albacore age and growth studies based on data obtained by tagging experiments and scale reading, respectively. Both Clemens and Bell fit their data to von Bertalanffy's growth equation. Their results are presented in Table IX and Figs. 12a and 12b.

### 3.5 Behavior

#### 3.5.1 Migration and local movements (see also section 5.3.1)

The migration of albacore within and among the three important fisheries in the North Pacific Ocean has been described in some detail by Clemens (1961) and Otsu and Uchida (MS). The account of the migration among the fisheries given by Otsu and Uchida is briefly summarized below and is illustrated in Fig. 13.

A varying portion of the 2-, 3-, and 4-year old fish and nearly all the older fish in the American fishery migrate westward each fall into the Japanese longline fishery. The remainder of the fish from the American fishery move westward into midocean waters of the North Pacific, some as far west as the fringe of the Japanese longline grounds. Those that move into the longline fishery tend to migrate southwestward and later enter the Japanese livebait fishery. The others will return to the American fishery the following season. Thus, some fish may be available to the American fishery for as many as 4 or 5 consecutive seasons.

Table IX

Albacore age and growth as estimated by tagging experiments and scale reading

| Age groups | Fork length (cm) | | Increment (cm) | |
|---|---|---|---|---|
| | Clemens (1961) | Bell (1962) | Clemens (1961) | Bell (1962) |
| I | 52 | 57.3 | 13 | 8.4 |
| II | 65 | 65.7 | 11 | 11.7 |
| III | 76 | 77.4 | 9 | 6.3 |
| IV | 85 | 83.7 | 8 | 4.1 |
| V | 93 | 87.8 | 7 | - |
| VI | 100 | - | 5 | - |
| VII | 105 | - | | |

Albacore enter the Japanese winter fishery from both the American fishery and the Japanese livebait fishery. Each spring, a large portion of these fish, age groups 2 through 5 years, migrate westward from the longline grounds into the livebait grounds, while a few separate and move eastward into the American fishery. The larger adults, 6 years old and older, move southward from the winter longline grounds into subtropical and tropical waters, to the spawning grounds of the North Pacific albacore.

#### 3.5.2 Schooling

In the eastern North Pacific, albacore are found in school groups (Clemens, 1961). A school group, as defined by Clemens, is a discrete cluster of albacore schools that, although sometimes widely scattered, appear loosely related by having a tendency to act in unison.

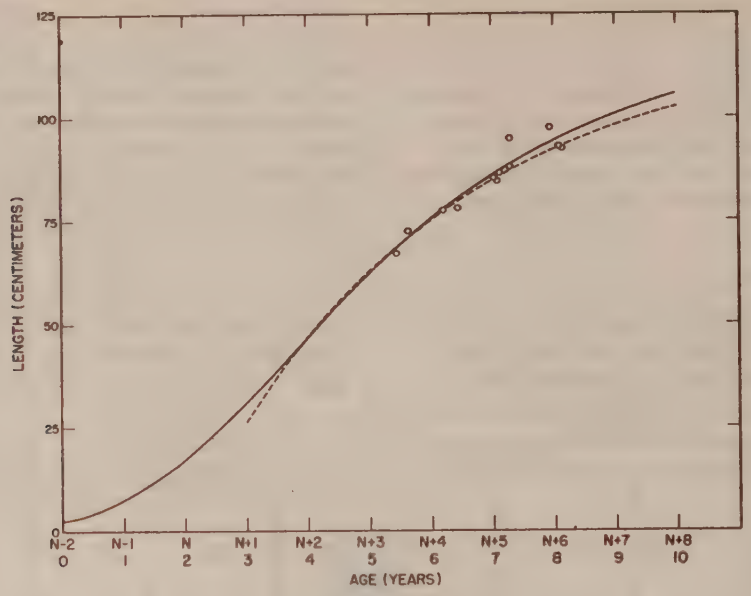


Fig. 10 Growth data fitted to a Gompertz equation by Riffenburgh's short method. The curve obtained by Walford's method (dashed) is superimposed. Observed data are superimposed on the Gompertz curve (Otsu, 1960)

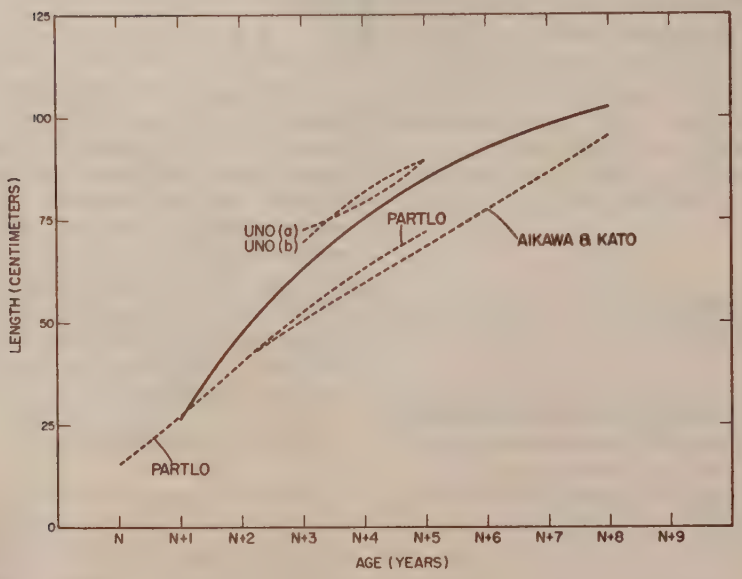


Fig. 11 A comparison of the growth curves obtained by the vertebral method with the Walford curve obtained in this study. Specific ages are disregarded in the plotting of these curves (Otsu, 1960)

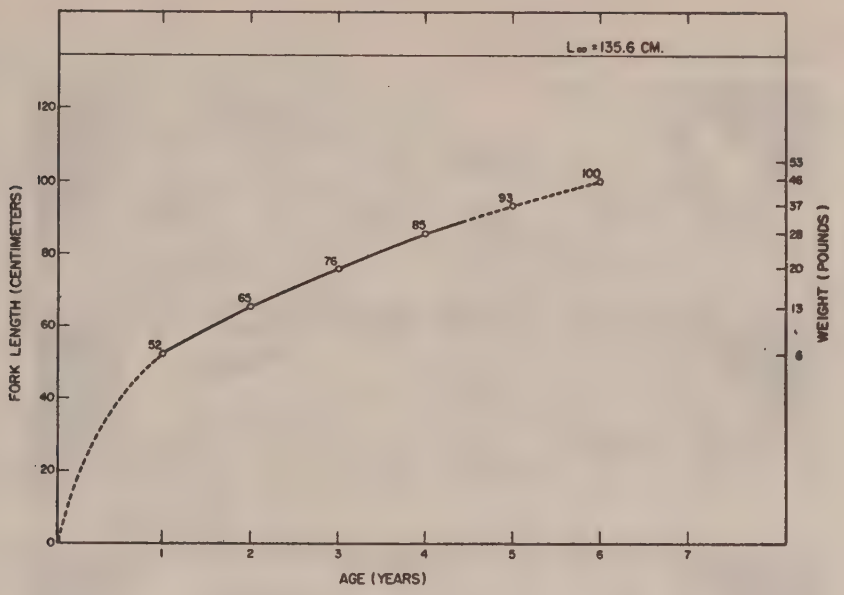


Fig. 12a Albacore weight-length-age curve based on 21 tag recoveries, 1952 through 1957 (Clemens, 1961)

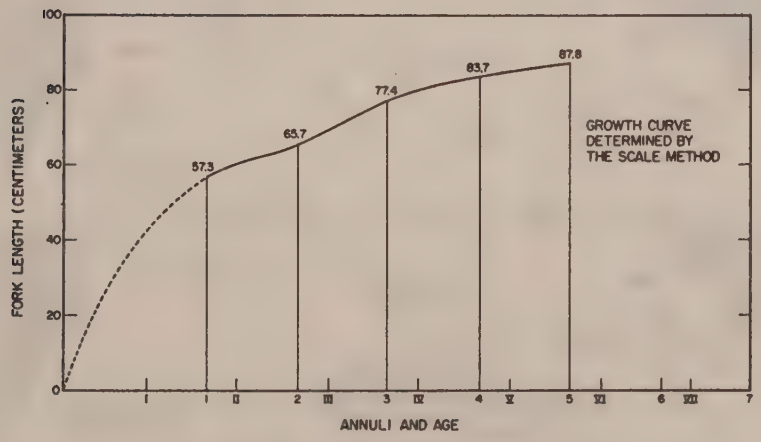


Fig. 12b Albacore growth curve. The scale of the abscissa represents months of the year. The first annulus is set hypothetically at February. The age is set at October. The intercept at y is set at March (Bell, 1962)

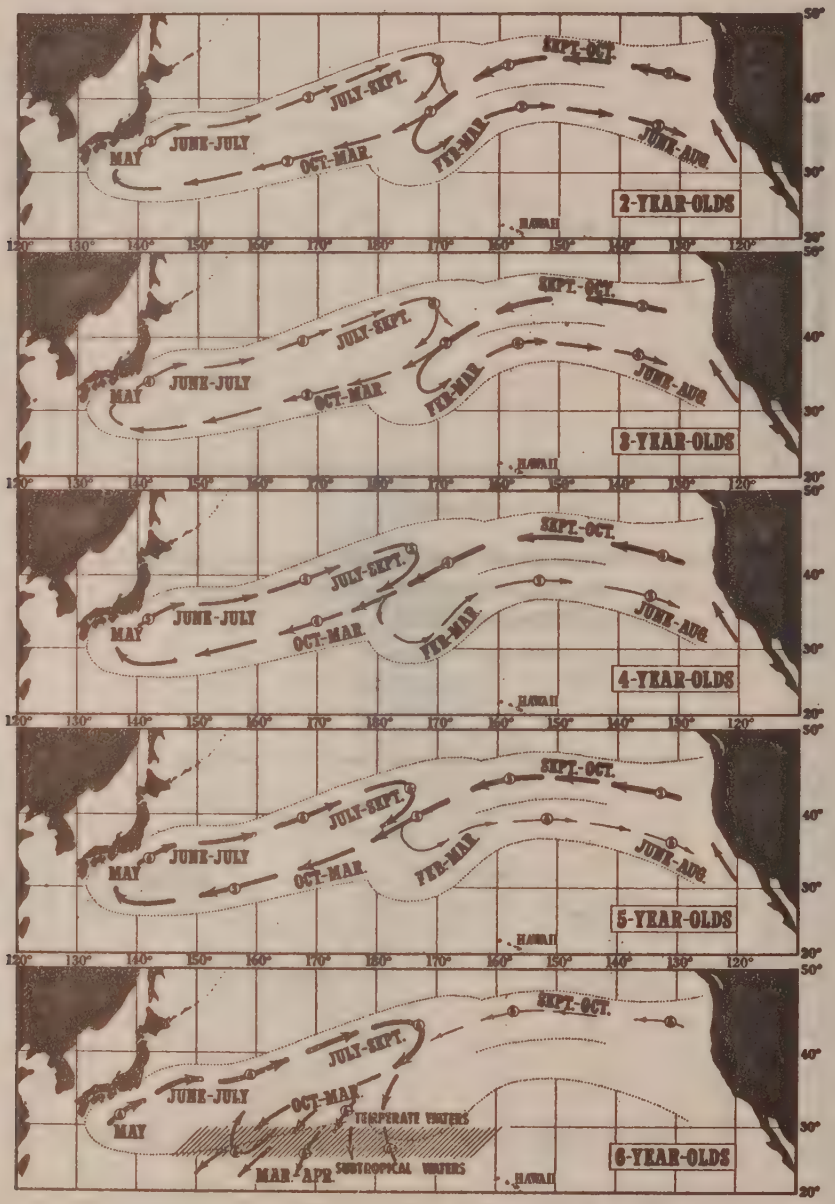


Fig. 13 Model of albacore migrations in the North Pacific Ocean, by age groups (ages encircled) (Otsu and Uchida, MS)

According to Clemens, at the beginning of the albacore season on the west coast of the United States, the school groups are widely separated and are composed of relatively few small, scattered, loosely knit, fast-traveling schools. During the peak of the season, although the individual schools are still somewhat loosely knit, they are larger. The school groups appear more compact and contain a greater number of schools. Albacore larger than 20 pounds usually are more compactly schooled than smaller fish and spend more time in deeper water.

The schools of albacore encountered off Japan appear to be generally small, perhaps partly because of the intensity with which they are harried and broken up by concentrated fleet action (Van Campen, 1960).

3.5.3. Reproductive habits (see section 3.1)

- Physiology

It is generally assumed that tunas, including albacore, have high metabolic rates. For example, Clemens (1961) states, "Albacore are fast-traveling, opportunistic feeders, with high metabolic rates and they need quatities of food." However, there is very little information in the literature on the metabolism or other facets of the physiology of albacore.

# 4 POPULATION (STOCK)

## 4.1 Structure

### 4.1.1 Sex ratio

Brock (1943) analyzed the size distribution by sex of a sample of Oregon albacore taken from July 30 to October 14, 1940. He noted a significant departure from a 1:1 male to female ratio for fish smaller than 67 cm (Fig. 14). He attributed this to incorrect determination of sex in a significant portion of fish smaller than 67 cm. The sex ratio of albacore larger than 67 cm did not differ significantly from 1:1.

Otsu and Uchida (1959a) noted that the sex ratio was nearly 1:1 for a sample of albacore caught in the central equatorial Pacific. In Hawaiian waters, however, they noted that the males predominated (Fig. 15). Otsu and Uchida (1959b) ascribed the unbalanced sex distribution among larger albacore largely to differential growth which sets in with the onset of sexual maturity, after which the males grow at a faster rate than the females.

Suda (1956) found that there was an extraordinarily high proportion of males in the North Equatorial Current area (western North Pacific) (Table X). Although Suda does not mention it, the size distribution of albacore by sex he presents (Fig. 16) also illustrates the differential growth of large albacore, as observed by Otsu and Uchida (1959b).

Other references to sex ratio of albacore are listed in Table XI.

Table X

Sex ratio of albacore in the North Equatorial Current area*
(Suda, 1956)

| Date of investigation | Locality | Male | Female | Ratio (♂/♀) |
|---|---|---|---|---|
| May 4-May 23, 1949 | 18°18' N -20°59' N 148°10'E -152°02' E | 84 | 40 | 2.1 |
| June 22-July 2, 1949 | 21°56' N -22°56' N 148°52' E -152°54' E | 59 | 26 | 2.3 |
| Mar. 5-Mar. 22, 1949 | 21°00' N -24°13' N 143°32' E -151°45' E | 14 | 6 | 2.3 |
| Feb. 14-Feb. 19, 1950 | 22°12' N -24°42' N 149°52' E -152°28' E | 17 | 3 | 5.7 |
| Mar. 26-Apr. 6, 1950 | 22°50' N -24°10' N 143°15' E -146°09' E | 56 | 9 | 6.2 |
| May 17-June 14, 1952 | 13°55' N -22°54' N 146°23' E -153°06' E | 10 | 12 | 0.8 |
| July 2-Aug. 1, 1952 | 10°08' N -24°04' N 150°23' E -158°43' E | 56 | 16 | 3.5 |
| | Total | 296 | 112 | 2.64 |

*Includes the individuals whose body length was not measured.

Table XI

Sex ratio of albacore

| Date | Locality | Sex ratio | Reference |
|---|---|---|---|
| Jan. 29-Mar. 12, 1952 | 08°00' S - 08°02' N 154°56' W - 179°50' E | 1 male:1.32 female | Murphy and Shomura (1953) |
| Oct. 17-Nov. 28, 1952 | 05°00' S - 21°11' N 150°39' W - 170°08' W | 1 male:1.6 female | Murphy and Shomura (1955) |
| Jan. 1959-July 1960 | New Caledonia | 27.5 percent females | Legand (MS) |

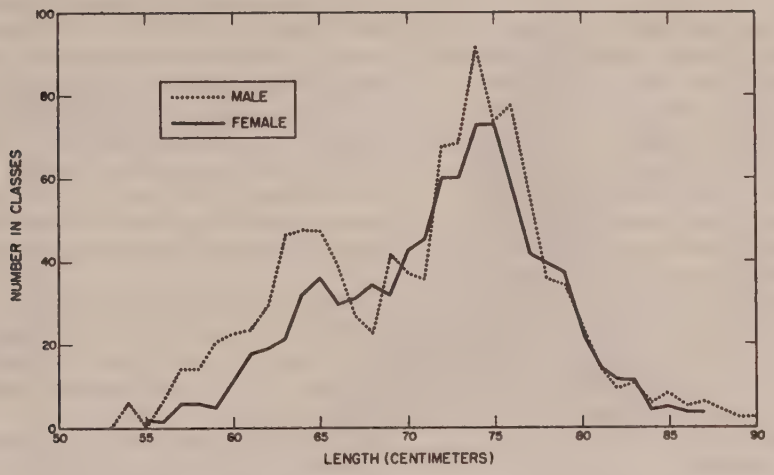


Fig. 14 Length-frequency curves of males and females, Oregon albacore (Brock, 1943)

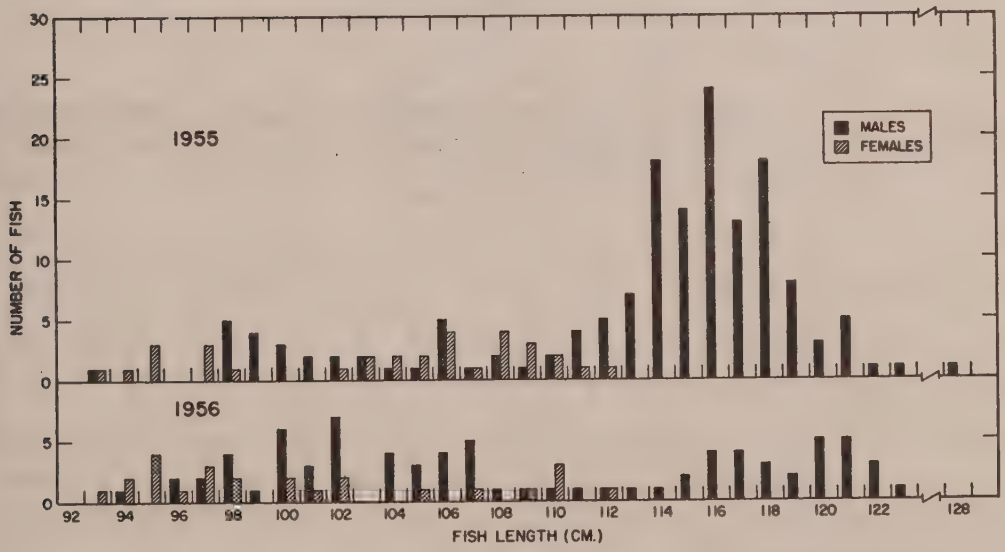


Fig. 15 Size and sex distribution of albacore sampled from landings in the Hawaiian Islands, (a) 1955 (b) 1956 (Otsu and Uchida, 1959a)

### 4.1.2 Age composition

In conjunction with studies on age and growth, attempts have been made to determine the age composition of the catches from the albacore fisheries in the temperate North Pacific. Uno (1963a) measured 1,500 albacore taken by pole-and-line fishing in the waters east of Cape Nojima, Japan during May to June 1935. He made age determinations on 300 of these fish and found that 6 percent were of age IV, 86 percent of age V, and 8 percent of age VI (Table XII). Based on the size distribution of these age groups he estimated that of the 1,500 fish sampled, 4 percent were age IV, 91 percent age V, and 5 percent age VI. Uno (1936b) sampled the same fishery the following year, during June, and made age determinations on 688 albacore (Table XIII).

Aikawa and Kato (1938) determined the ages of 10 large albacore taken near Midway Island and 5 small albacore taken off northeastern Japan, and calculated the size and weight ranges of albacore at different ages. They present a size frequency distribution of albacore caught between 28° - 34° N, 170° - 173° E, and suggest that the modes at 25 cm, 45 cm, 56 cm, 62 cm, 74 cm, and 83 cm correspond respectively to age classes from fish of the year to the sixth year (Fig. 17).

In the British Columbia albacore fishery, Partlo (1955) points out that four size groups were represented in the catches during 1949, 1950 and 1951. The average lengths of these size groups were 54.3, 62.9, 71.7 and 81.9 cm and the corresponding ages were III, IV, V and VI (Table XIV and Fig. 18).

Table XII

Age composition of albacore (from Uno, 1936a)

| Date landed | Number landed | Number of age determinations | | | Totals | Age composition (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | Age IV | Age V | Age VI | | Age IV | Age V | Age VI |
| (1) V. 1 - V. 19 | 15,500 | 4 | 35 | 1 | 40 | 10 | 87 | 3 |
| (2) V. 20 - VI. 2 | 89,863 | 3 | 67 | 2 | 72 | 4 | 93 | 3 |
| (3) VI. 3 - VI. 10 | 62,355 | 8 | 42 | 0 | 50 | 16 | 84 | - |
| (4) VI. 11 - VI. 17 | 21,555 | 0 | 65 | 5 | 70 | - | 93 | 7 |
| (5) VI. 18 - VI. 30 | 13,344 | 2 | 51 | 15 | 68 | 3 | 75 | 22 |
| | 202,617 | 17 | 260 | 23 | 300 | 6 | 86 | 8 |

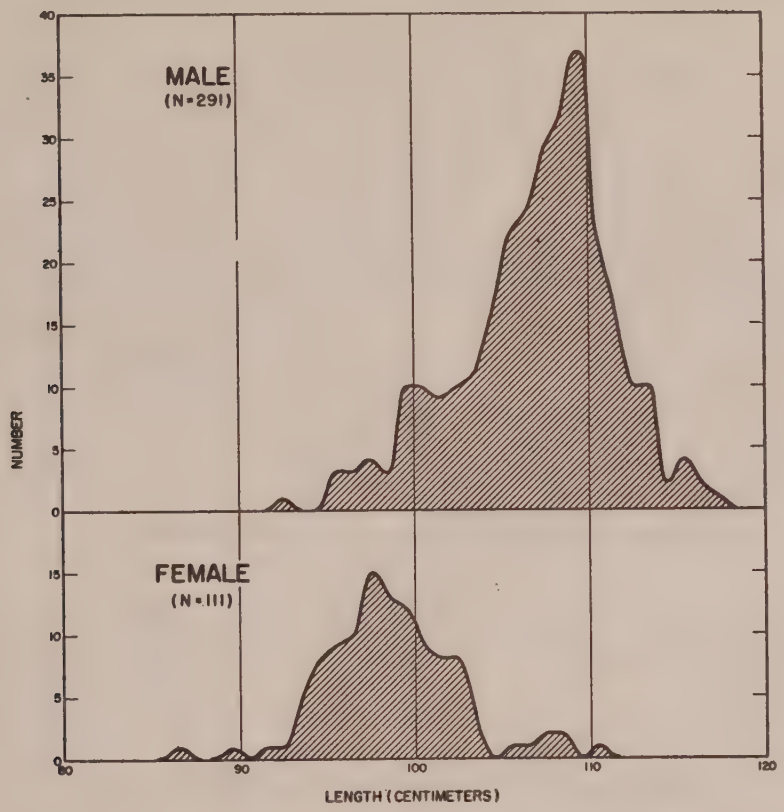


Fig. 16 Length frequency of males and females caught in the North Equatorial Current Area (Suda, 1956)

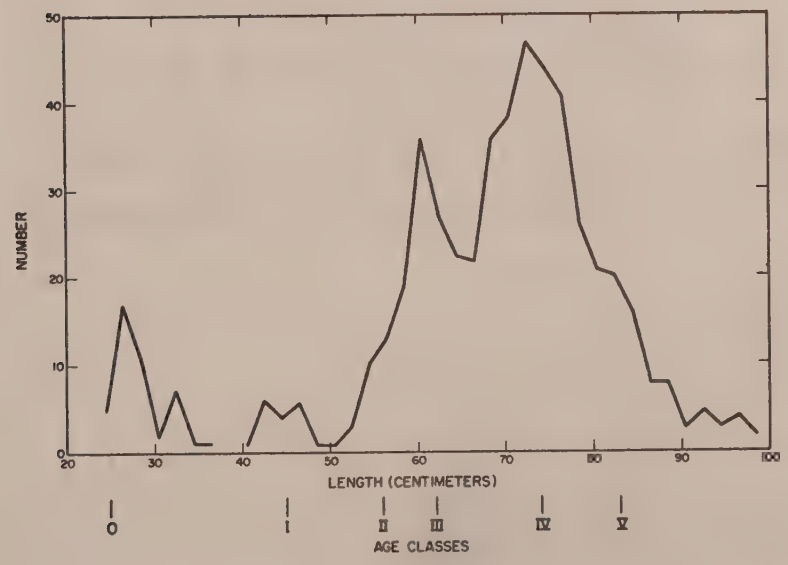


Fig. 17 Age composition of a sample of albacore caught between 28°-34° N., 170°-173° E. (Aikawa and Kato, 1938)

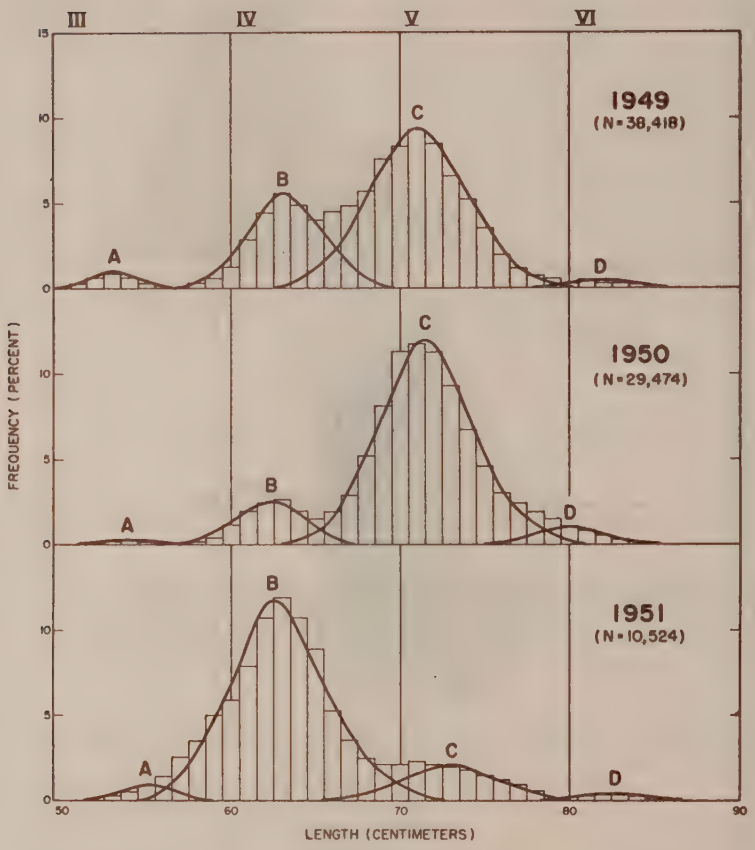


Fig. 18 Comparison of length frequency distribution of the 1949, 1950 and 1951 British Columbia albacore catches (Partlo, 1955)

Table XIII

Age composition of albacore (from 1936b)

| | Body length (cm) | | | | | | Body weight (kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age IV | | Age V | | Age VI | | Age IV | | Age V | | Age VI | |
| | M | S D | M | S D | M | S D | M | S D | M | S D | M | S D |
| (1) | 72.70 | 0.73 | 79.32 | 4.22 | 88.00 | ? | 8.075 | 1.546 | 9.924 | 2.040 | 14.150 | ? |
| (2) | 72.50 | 1.81 | 78.80 | 2.81 | 88.30 | 0.50 | 7.950 | 0.071 | 9.496 | 1.040 | 12.925 | 0.177 |
| (3) | 72.06 | 1.26 | 79.25 | 3.32 | - | - | 8.287 | 0.415 | 9.260 | 0.750 | - | - |
| (4) | - | - | 80.21 | 3.42 | 88.40 | 0.92 | - | - | 11.049 | 1.340 | 13.720 | 0.352 |
| (5) | 73.35 | 0.84 | 81.57 | 3.84 | 90.22 | 2.49 | 7.575 | 0.079 | 10.488 | 1.670 | 13.276 | 1.800 |
| | 72.38 | 1.30 | 79.15 | 3.68 | 89.55 | 2.25 | 8.094 | 0.824 | 10.149 | 1.520 | 13.380 | 1.490 |

| Date landed | Number of age determinations | | | Totals | Age composition (%) | | |
|---|---|---|---|---|---|---|---|
| | Age IV | Age V | Age VI | | Age IV | Age V | Age VI |
| VI.1 - VI.9 | 69 | 252 | 44 | 365 | 18.9 | 69.0 | 12.1 |
| VI.10- VI.15 | 23 | 111 | 18 | 152 | 15.2 | 73.0 | 11.8 |
| VI.16- VI.20 | 21 | 119 | 31 | 171 | 12.3 | 69.6 | 18.1 |
| Totals | 113 | 482 | 93 | 688 | 15.5 | 70.5 | 14.0 |

| Age group | Body length (cm) | | Body weight (kg) | |
|---|---|---|---|---|
| | M | S D | M | S D |
| IV | 69.04 | 4.65 | 7.607 | 0.815 |
| V | 81.56 | 3.82 | 11.774 | 1.670 |
| VI | 89.70 | 1.98 | 15.192 | 0.948 |

Table XIV

Percentage composition, mean length, standard deviation, standard error of the mean, and availability (fish per boat-hour fished) of component size-groups of the 1949, 1950, and 1951 British Columbia Albacore Catches. Total availability estimates for each year are included (Partlo, 1955)

| Year | Total availability | Size group | Percentage composition | Mean length (cm) | S D | S E | Availability |
|---|---|---|---|---|---|---|---|
| 1949 | 5.04 | A | 3.05 | 53.25 | 1.35 | 0.040 | 0.15 |
| | | B | 28.95 | 63.30 | 2.07 | 0.020 | 1.46 |
| | | C | 65.50 | 71.10 | 2.82 | 0.018 | 3.30 |
| | | D | 2.50 | 82.95 | 2.87 | 0.093 | 0.13 |
| 1950 | 3.39 | A | 0.40 | 54.27 | 1.75 | 0.160 | 0.01 |
| | | B | 11.90 | 62.35 | 2.05 | 0.030 | 0.40 |
| | | C | 80.70 | 71.35 | 2.62 | 0.017 | 2.74 |
| | | D | 7.00 | 79.70 | 2.37 | 0.05 | 0.24 |
| 1951 | 2.19 | A | 3.50 | 55.25 | 1.65 | 0.086 | 0.08 |
| | | B | 81.50 | 62.90 | 2.75 | 0.029 | 1.78 |
| | | C | 13.10 | 72.75 | 2.75 | 0.074 | 0.29 |
| | | D | 1.90 | 82.95 | 3.02 | 0.214 | 0.04 |

All the studies listed above were based on determining the age of albacore by reading marks on the vertebrae. There is some doubt about validity of that method, for Otsu and Uchida (1959b) found that they could not satisfactorily duplicate the results of the earlier workers.

However, size frequency analyses of albacore catches in the temperate North Pacific have indicated that the various size groups appearing in the fisheries can be regarded as year-classes (Brock, 1943; Suda 1954). Furthermore, growth data obtained from tagging experiments have corroborated these observations (Otsu, 1960; Clemens, 1961).

Otsu and Uchida (MS) and Uchida and Otsu (MS) have estimated the ages of the different size groups occurring in the various fisheries, based on growth data derived from tagging experiments and other information (Fig. 19). An estimate of the percentage composition, by number, of each age group occurring in the albacore fisheries in the Pacific Ocean is found in Table XVI.

Bell (MS) gives the age composition of the albacore catch during September-November 1959 in California (Table XV). It should be pointed out that there is a discrepancy of one year between the age estimates made by Bell and Otsu and Uchida (MS). Therefore, although it is generally agreed that the size groups of albacore are year-classes, there is still no agreement on the absolute ages of these year-classes.

### 4.1.3 Size composition

The size composition of the catches of albacore in the various fisheries in the Pacific Ocean is well documented. In general, each fishery is dependent on certain characteristic size groups, which appear rather regularly each year. Uchida and Otsu (MS) summarized published and some unpublished data on albacore size frequency distributions into composite size frequency distributions for the fisheries in the Pacific Ocean (see Fig. 19).

Mimura (1957) has reported on the size composition of the catches of albacore in the Indian Ocean (Figs. 20a and b).

13/ Bell, Robert R., MS. The age composition of the California Pacific albacore catch. Presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.

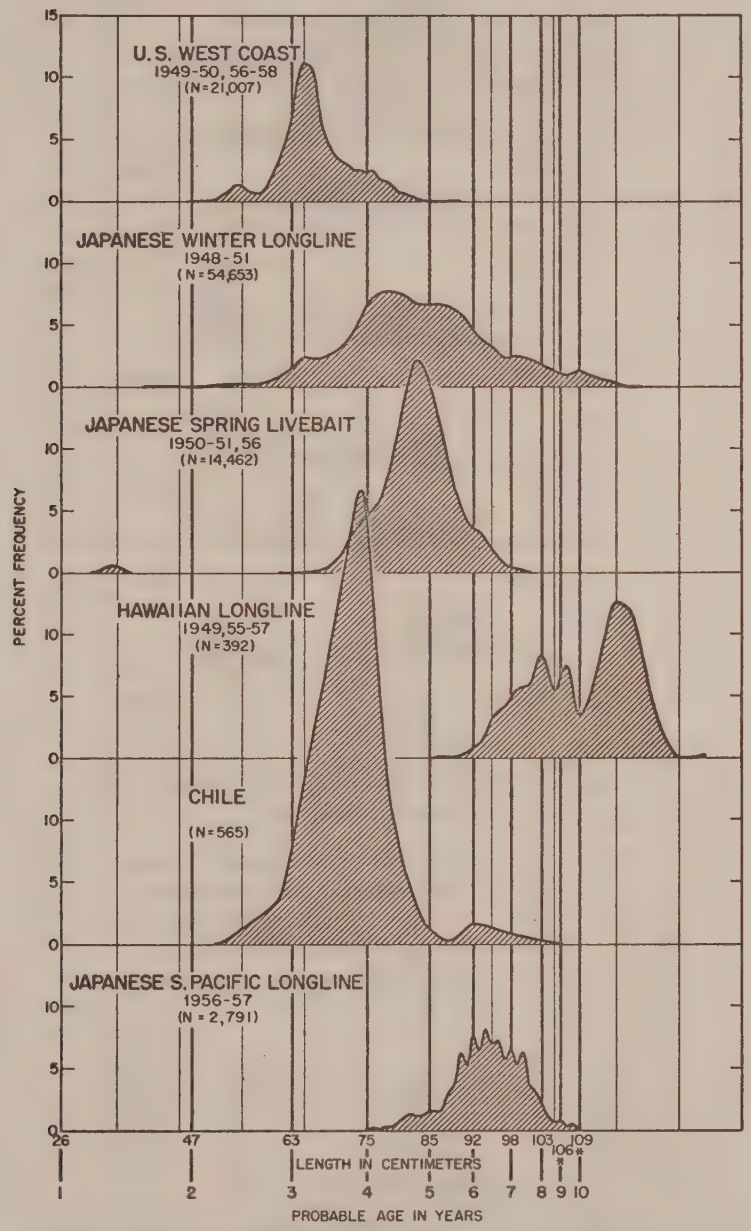


Fig. 19 Combined length frequency distribution separated into component age groups using growth rates derived by Otsu (1960) (Uchida and Otsu, MS)

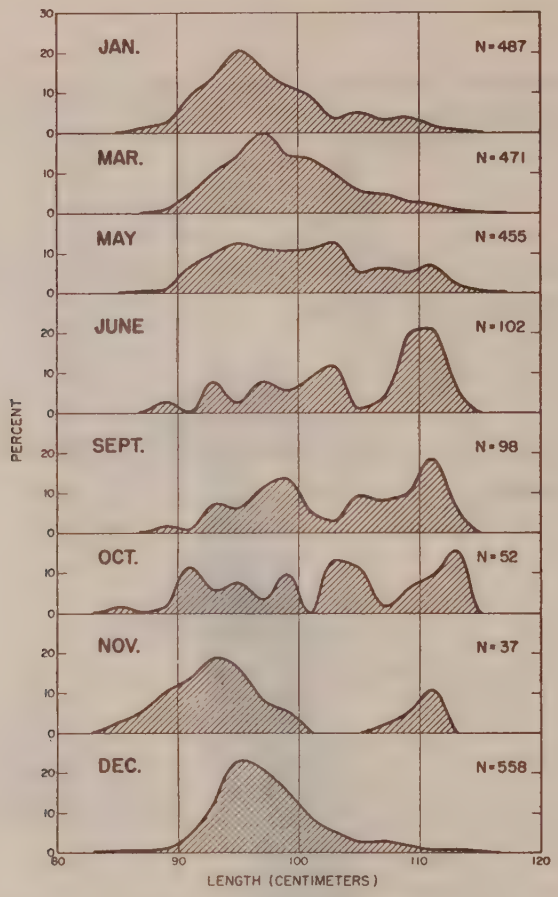


Fig. 20a Length frequency of albacore by month, caught in the South Equatorial Current Area (9°-25° S, 90°-120° E) (Mimura, 1957)

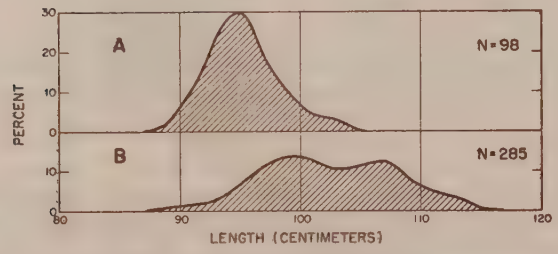


Fig. 20b Length frequency of albacore, caught in the Equatorial Area, (a) 0°-3° N, 1955, Apr. Jun., (b) 0°-4° S, 1955, Apr. (Mimura, 1957)

Table XV.

The age composition of the catch - September, October, November 1959
(adapted from Bell, MS)

| Fork length (cm.) | Number of fish, by age, in the catch | | | | |
|---|---|---|---|---|---|
| | I | II | III | IV | V |
| 44 | 233 | | | | |
| 51 | 466 | | | | |
| 52 | 2,331 | | | | |
| 53 | 3,330 | 1,332 | | | |
| 54 | 6,993 | 1,165 | | | |
| 55 | 16,081 | | | | |
| 56 | 11,012 | 3,671 | | | |
| 57 | 17,196 | 2,149 | | | |
| 58 | 11,071 | 2,214 | | | |
| 59 | 11,265 | 2,253 | | | |
| 60 | 13,285 | 4,428 | | | |
| 61 | 9,012 | 18,024 | | | |
| 62 | 5,461 | 32,762 | | | |
| 63 | 10,848 | 48,317 | | | |
| 64 | 15,344 | 76,717 | | | |
| 65 | | 108,842 | | | |
| 66 | 20,714 | 89,759 | | | |
| 67 | 10,365 | 62,187 | 10,365 | 5,182 | |
| 68 | | 48,925 | 4,447 | | |
| 69 | | 17,784 | 11,116 | | |
| 70 | | 8,823 | 3,529 | | |
| 71 | | 5,827 | 2,331 | | |
| 72 | | 1,199 | 2,996 | | |
| 73 | | | 4,429 | | |
| 74 | | 599 | 2,997 | 599 | |
| 75 | | | 5,360 | | |
| 76 | | 1,166 | 3,496 | | |
| 77 | | | 4,661 | 932 | |
| 78 | | 1,099 | 4,395 | 2,197 | |
| 79 | | 1,224 | 6,118 | 2,447 | |
| 80 | | | 3,088 | 7,720 | 1,544 |
| 81 | | | 7,738 | 11,607 | |
| 82 | | | 9,230 | 13,844 | |
| 83 | | | 7,924 | 11,887 | |
| 84 | | 2,823 | 2,823 | 19,759 | |
| 85 | | | 2,963 | 14,817 | 2,963 |
| 86 | | | 3,329 | 4,995 | 3,329 |
| 87 | | | 1,398 | 4,195 | 2,098 |
| 88 | | | 1,010 | 4,040 | 1,010 |
| 89 | | | 1,332 | 333 | 666 |
| 90 | | | | 1,048 | 350 |
| 91 | | | | | 233 |
| 92 | | | | 233 | 233 |
| 93 | | | | | 233 |
| 94 | | | | 233 | |
| 95 | | | | | 233 |
| 96 | | | | | |
| 97 | | | | | 233 |
| 98 | | | | | 233 |
| Totals | 165,007 | 543,789 | 107,075 | 106,068 | 13,358 |

Table XVI

Percentage composition, by number of each age group occurring in the catches of the albacore fisheries in the Pacific (Uchida and Otsu, MS)

| Age (years) | North Pacific | | | South Pacific | |
|---|---|---|---|---|---|
| | United States | Japanese winter longline | Japanese spring livebait | Japanese longline 0° - 30° S | Chile |
| 1 | - | < 0.1 | 1.0 | - | - |
| 2 | 17.6 | 2.1 | < 0.1 | - | 5.7 |
| 3 | 70.8 | 16.2 | 5.5 | 0.1 | 76.1 |
| 4 | 11.4 | 35.6 | 50.4 | 5.9 | 15.4 |
| 5 | 0.2 | 24.7 | 37.2 | 22.2 | 1.7 |
| 6 | - | 9.5 | 5.7 | 41.7 | 0.9 |
| 7 | - | 4.7 | 0.2 | 24.8 | 0.2 |
| 8 | - | 3.1 | <0.1 | 4.0 | - |
| 9 | - | 2.2 | - | 1.3 | - |
| 10 | - | 1.9 | - | 0.1 | - |

4.2 Size and density

4.2.1 Average size

No one, insofar as is known, has attempted to make estimates of the size of the albacore populations in the Pacific or Indian Oceans.

4.2.2 Changes in size

Otsu (1959) surveyed the fisheries of the North Pacific for the period 1930-1957 and made a few observations on their condition. Although he did not give absolute numbers, he stated that "it seems unlikely that the exploitation has seriously affected the albacore stock" and "there is no indication of a declining resource."

4.3 Natality and recruitment (see section 4.5)

4.4 Mortality, morbidity

4.4.1 Rates of mortality

Tauchi (1940), on the basis of the size composition of albacore catches during 1934-1937 in Japan, estimated that the survival rate was .66, the fishing rate about .18, and the natural mortality rate .20.

4.5 Dynamics of population

Suda (1958) made a study of the "interchange" of albacore in the Japanese North Pacific fisheries. He defines "interchange" as the recruitment and dispersion of albacore into the exploited population. Suda found that the interchange of albacore in the North Pacific fishing grounds takes place once a year around March and that the fishing condition of the following year is greatly influenced by this interchange.

In a later report Suda (1959) examined the recruitment phase of the interchange in greater detail. Suda calculated an index S, which is an estimate of the magnitude of recruitment of a year class into the fishing ground. This index was calculated from data obtained from the longline fishery. Suda also calculated an index C, which is an estimate of the total number of albacore caught by both the longline and livebait fisheries. He found that although there is some relationship in the relative magnitude of index S and C, index C does not agree perfectly with index S. He also found that the yearly variation in recruitment was very large; that after a certain level of index S was attained, it tended to be maintained for several years; that there was a tendency for a clear biennial variation during a period of generally high level of recruitment, which become obscure during periods of low recruitment; that there was no definite relation between the size of the spawning group and the size of the recruitment.

4.6 Relation of population to community and ecosystem, biological production etc.

From his study of the recruitment of albacore in the Japanese North Pacific fisheries, Suda (1959) concluded that there seem to be variations in the basic productive potentials of the sea area inhabited by albacore larvae. He based this conclusion partly on the observation that after a certain magnitude of recruitment was attained, this magnitude tended to be maintained for several years and that the size of the spawning group was not related to the size of recruitment.

# 5 EXPLOITATION

## 5.1 Fishing equipment

### 5.1.1 Fishing gear

The U.S. west coast fishery takes albacore by trolling and livebait fishing. The trolling gear consists of a 20- to 30-foot pole, usually eucalyptus, rigged on each side of the boat, to which several lines with fishing lures are attached A detailed description of the trolling gear is given by Scofield (1956).

The gear used in the livebait fishing method consists of a bamboo pole with a barbless hook at the end of a 6-foot line. The pole averages between 8 and 9 feet in length, varying according to the size of the fish being caught and the preference of the fishermen. The gear and fishing method are essentially similar to that described by Godsil (1938) for the yellowfin and skipjack livebait fishery in the eastern Pacific.

In general, the fishing gear used in the Japanese livebait fishery for albacore is similar to that used on the U. S. west coast. A detailed description of the gear and fishing methods is given by Cleaver and Shimada (1950).

Longline gear is used in the Japanese winter fishery, the fishery based at Samoa and the New Hebrides in the South Pacific, the fishery in the Indian Ocean, and the Hawaiian fishery. The gear probably differs only in minor details in the various fisheries. The following excerpt describing longline gear is taken from Shimada (1951).

"The basic unit of longline fishing gear is the 'basket'. A basket consists of several sections of main or trunk line, usually cotton, to which are tied a number of branch lines and a float line (Fig. 21). Each branch line is made up of a length of cotton line; or a 'sekiyama' or 'shanawa' (cotton thread wound around a core of wire or fiber); a wire leader and hook. Lines, including the 'sekiyama', are coated with tar to prevent deterioration and to add rigidity for ease of handling.

"The baskets are tied in one continuous line when a set is made. Glass or metal floats, varying in diameter from 10 to 12 inches, are used to buoy the main and branch lines at subsurface level."

### 5.1.2 Fishing boats

In the U.S. west coast fishery there apparently are no boats that may be called "typical" albacore livebait or trolling boats. According to Clemens (1955), the fishery comprises vessels of myriad sizes, shapes, and descriptions using two types of gear, livebait and trolling. The smaller boats usually under 30 feet in length, catch fish by trolling, while the larger boats, usually over 30 feet in length, are equipped for livebait fishing (Fig. 22).

The following, taken from Van Campen (1960), is a brief description of the type of boat used in the Japanese livebait fishery.

"The most conspicuous characteristics of these craft are the long, high bowsprit bearing prolongations of the fishing racks, the racks extending along one or both sides of the vessel and around the stern, only about 1 foot below the high gunwale, and the spray-system pipes, with closely spaced nozzles, paralleling the racks. The superstructure is all abaft the beam, and the long open welldeck has 9 or 12 hatches. Those hatches along the sides lead to the iced fish holds and those along the midline open into the live wells. Pump circulation for bait wells has not yet caught on in Japan, and the practice of circulating the water through simple openings in the vessel's bottom is almost universal in Japanese bait boats. Most of the boats of less than 130 tons gross are of wooden construction; all of the larger ships are steel." (Fig. 23).

"The typical Japanese longline vessel resembles an Atlantic well-deck trawler and is characterized by a strong shear line (Fig. 24). Power is usually supplied by a Diesel engine and, in many cases, auxiliary gaff-rigged sails are also carried to supplement the main engine. The wheelhouse is located amidships and the engine room is aft. This setup provides ample working space forward, which is free of excess deck structures, except for the longline hauler which may be situated on the port or starboard side. Often, two longline haulers are so installed that fishing gear may be taken in from either side. Removable doors are cut into the bulwark for bringing fish and gear aboard." (Shimada, 1951).

Otsu (1954) gives a description of the boats used in the Hawaiian longline fishery. Briefly, the boats are built along the lines of the Japanese sampan-type livebait boats, with a high

and narrow bow, a modified V-bottom, and a moderately low freeboard aft. The afterdeck has sufficient space for handling the fishing gear efficiently. The boats range in size from 40 to 63 feet in over-all length, with about a 12-foot beam and a 6 foot draft on 60-foot boats. They are powered with a Diesel main engine of 115 to 165 horsepower, usually of the high-speed type, driving a single screw through a reduction gear (Fig. 25).

In Chile, the albacore fishing boats are generally 7.20 meters long, 0.62 meters deep, with a beam of 1.50 meters, and are called "bongos". Power is supplied by outboard motors (de Buen, 1958).

## 5.2 Fishing areas

### 5.2.1 General geographic distribution

The general localities of the major Pacific and Indian Ocean albacore fisheries are shown in Fig. 26a and 26b.

### 5.2.2 Geographical ranges (latitudes, distances from coast, etc.)

Clemens (1961), in speaking of albacore says, "In the eastern North Pacific individuals have been recorded off Mexico's mainland at Clarion Island, of the Revilla Gigedo Islands group, and northward along coastal Baja California, California, Oregon, Washington, British Columbia, and in the Gulf of Alaska. The most productive fishing grounds, however, lie between central Baja California and the Columbia River."

The fishing grounds of the Japanese livebait albacore fishery are in the form of an arc averaging about 200 to 300 miles in breadth and extending from around 30° N, 140° E to 32° - 33° N, 160° - 165° E. The extreme western end of the grounds is within 100 miles of port and the extreme eastern end is over 1,000 miles away (Van Campen, 1960).

The longline fishing grounds for albacore in the South Pacific extend from about 10° N to 30°S latitude and from about 140° W to 160° E longitude. This area is fished by Japanese and a few Korean longliners operating out of Samoa and the New Hebrides, Japanese longline boats which operate in mothership fleets, and independently operating longliners (Otsu, 1959).

In the Indian Ocean there are two longline fishing grounds for albacore. One is located between 5° N and 5° S latitude, stretching from about 50° E to 100° E longitude. The other extends from about 8° S to 25° S latitude and from 50° E to 120° E longitude (Mimura, 1957).

In the Pacific Ocean, other localities where albacore are exploited commercially are the waters off Chile, Australia and around the Hawaiian Islands. However, the landings of these fisheries constitute only a small portion of the total albacore landings in the Pacific Ocean.

In the Chilean fishery, the area of largest catches covers central Chile, in the provinces of Aconcagua and Valparaiso, and exceptionally albacore may be taken off Taltal, and to the south as far as Talcahuano (de Buen, 1958). This fishery is conducted within 15 miles of the coast (Manning, undated report).

The longline fishery in Hawaii, which takes albacore only incidentally with other more numerous species of tunas and spearfishes, is confined to within 20 miles of the island (Otsu, 1954).

In Australia, albacore are taken on the southeastern coast from Port Macquarie in New South Wales on the north to Westernport in Victoria on the south. It is also caught on the east and south coast of Tasmania and on the south coast of western Australia (Roughly, 1951).

### 5.2.3 Depth ranges

Albacore are caught at the surface by trolling or livebait fishing on the U.S. west coast, and in the Japanese livebait, the Chilean and the Australian fisheries.

Deep-swimming albacore are caught by longline gear in the Japanese winter fishery in the North Pacific, in the Indian Ocean fishery, the fishery in the South Pacific, and around the Hawaiian Islands. Although longline gear fishes subsurface levels, the absolute depths fished by the gear has not been reliably determined. However, it has been shown that in the central equatorial Pacific, albacore are generally caught in greater numbers on the relatively deeper fishing hooks of the longlines (e.g., Murphy and Shomura, 1953).

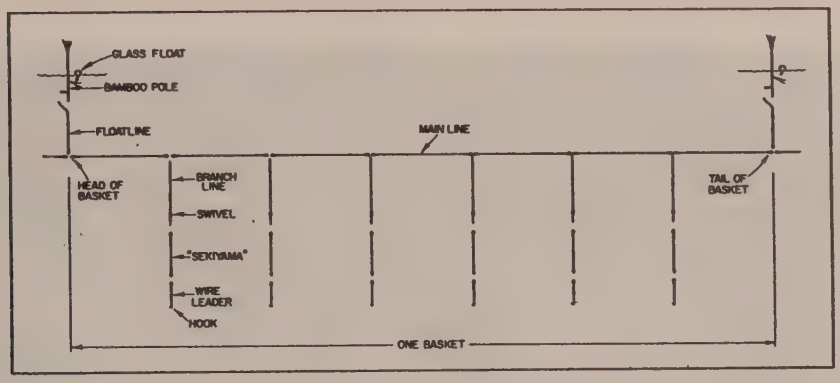


Fig. 21 Diagram showing the component parts of a basket of tuna longline fishing gear (Shimada, 1951)

Fig. 22 U. S. west coast albacore boats (photograph courtesy of Harold B. Clemens, California Department of Fish and Game)

Fig. 23 Japanese livebait fishing boat

Fig. 24 Japanese longline fishing boat

Fig. 25 Hawaiian longline fishing boat

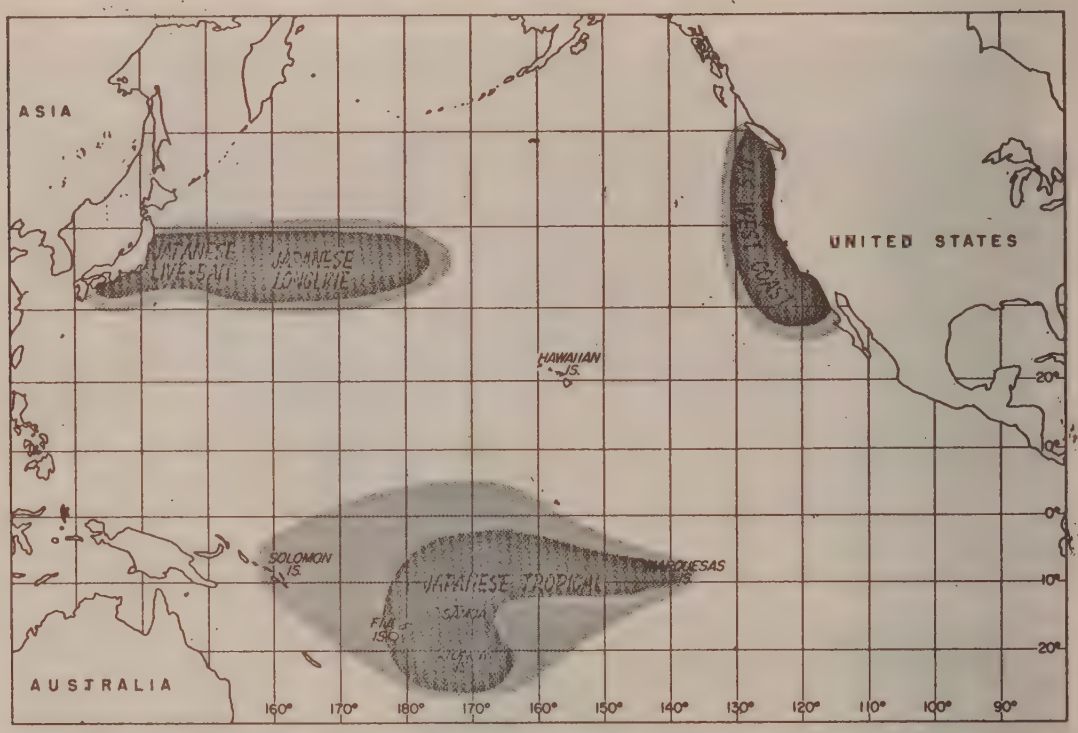


Fig. 26a General localities of the major Pacific albacore fisheries (Otsu, 1959)

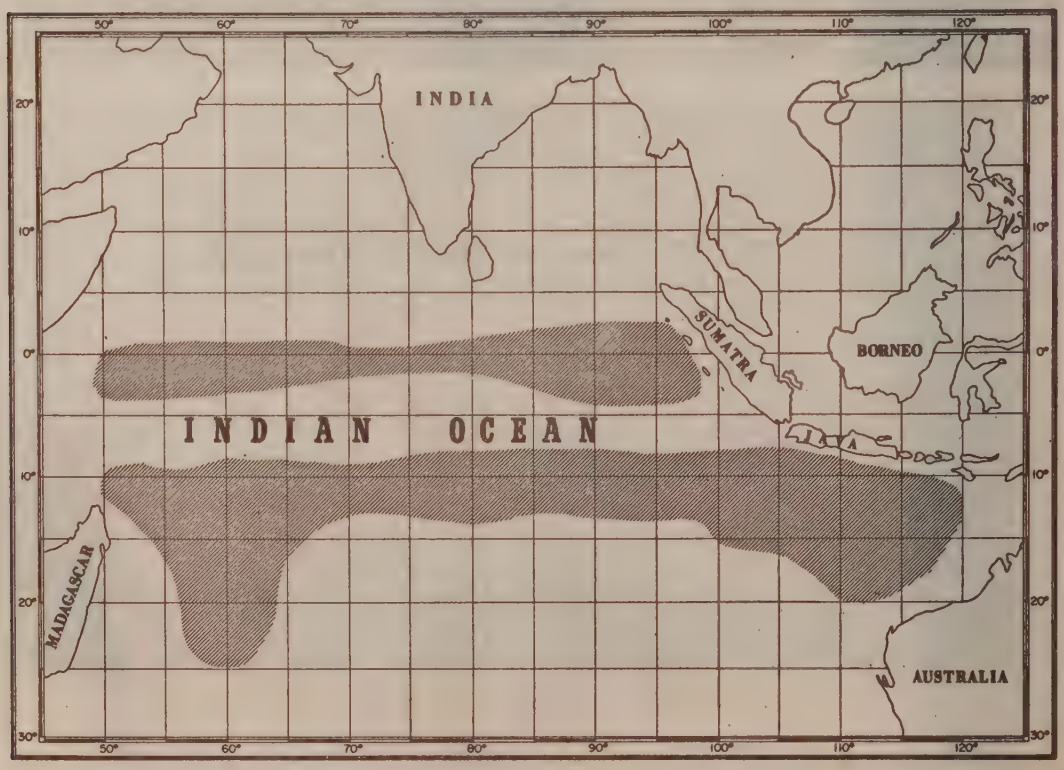


Fig. 26b Fishing grounds of albacore in the Indian Ocean (Mimura, 1957)

Shomura and Otsu (1956) reported on exploratory longline fishing for albacore in the central North Pacific. The albacore catches by relative depths of capture showed that, in general, albacore were caught in equal numbers throughout the range of fishing depths, a different situation from that of the central equatorial Pacific. Shomura and Otsu suggested that the difference in the vertical distribution of the North Pacific albacore and equatorial albacore may be associated with the difference in water temperatures between the two areas. The water temperatures which occur at the surface in the North Pacific are found in deeper layers near the Equator.

## 5.3 Fishing seasons

### 5.3.1 General pattern of fishing season

The Japanese livebait fishery begins off southern Japan, gradually moves north and northeast, and ends far offshore at about 160° E longitude (Van Campen, 1960).

The Japanese longline fishery begins in mid-ocean generally between 170° E and the 180th meridian and along 38° N latitude. There is a gradual southwestward shift of the areas of highest catch rates. Towards the end of the fishing season the center of concentration shifts to around 30° N latitude, 140° E longitude (Nakamura, 1951; Suda, 1954).

The American fishery tends to move northward up the coast and off-shore as the season progresses (Clemens, 1955).

### 5.3.2 Duration of fishing season (See section 5.3.3)

### 5.3.3 Dates of beginning, peak, and end of season

In the United States west coast albacore fishery, typically, the fishery buds in June, develops very rapidly in July, is in full bloom by August and September, wanes during October and November, and finally dies in December. In exceptional years fish are caught from May through January (Clemens, 1955).

The normal seasonal pattern of development of the Japanese summer fishery for albacore is for sporadic catches of small numbers of fish to begin in March and continue through much of April. Sometime between the latter part of April and the end of May the first large catches are made. By the middle of June the landings rise steeply to their peak of the season. In July the landings decline rapidly and by the end of July the season is virtually over (Van Campen, 1960).

The Japanese winter longline fishery is conducted between November and April over a broad area of the North Pacific. The season reaches a peak, in general, between December and February (Suda, 1954).

Albacore are caught throughout the year in the South Pacific longline fishery. There is no clear seasonal variation in landings, but the more productive months appear to be from August through February (Otsu, 1959).

In the Indian Ocean, the fishing season extends from April to September in the albacore fishing grounds straddling the Equator. On the grounds south of 8°S latitude, albacore are fished throughout the year. The catch rates here are higher during April through September than during the rest of the year (Mimura, 1957).

### 5.3.4 Variation in time or duration of fishing season

Apparently during certain years some albacore remain along the United States west coast over the winter. According to Clemens (1961), during the winter of 1955-56 a few albacore were caught in December, January, and early February. During the winter of 1956-57 some were taken from December through April; and in 1957-58 albacore were caught in December, January, February, March, and May.

The seasonal patterns of the Japanese livebait and longline fisheries described in the sections above are overly simplified versions of a more complex picture. Van Campen (1960) pointed out that while Japanese writers often imply that all pole-and-line fishing is done in the spring and summer and all longlining in winter, some albacore are taken by both methods in all months of the year.

### 5.3.5 Factors affecting fishing season

Clemens (1961) discusses in some detail the movements of albacore in relation to surface water temperatures off the United States west coast, which has an effect on the fishing season.

He points out that there is a definite albacore catch-temperature relationship in the eastern North Pacific. In the past a majority of the albacore has been caught while traveling within the narrow temperature range of 60° - 67° F. The development of these surface water temperatures seems to play a part in the movement of albacore along the coast, which in turn affects the development of the fishery.

In Japan also the way in which the pattern of surface temperature distribution develops is thought to affect the summer albacore fishing season. It is believed that the manner in which the warm Kuroshio pushes northward, resulting in isolated masses of water with suitable temperatures close to the coast of Japan, favors successful fishing (Van Campen, 1960). According to Sasaki (1939) albacore are taken in waters ranging from 18° to 24° C in temperature and the range of favorable temperatures is 19° to 23° C.

## 5.4 Fishing operations and results

### 5.4.1 Effort and intensity

Otsu (1960) made a survey of the American and Japanese albacore fisheries in the Pacific and noted that "it has not been possible to compile satisfactory statistics on fishing effort to be examined in relation to gross landings statistics." However, he noted that following Second World War the Japanese have continued to enlarge their fishing fleets, and have built larger vessels capable of fishing more distant waters. Table XVII, taken from Johnson (1959), illustrates the growth of the Japanese tuna fleet.

Table XVII

Increase in size of Japanese Tuna Fleet, 1947-56. (Johnson, 1959)

| Year | Vessels | Gross tonnage | Average gross tonnage |
|---|---|---|---|
| 1947 | 1,314 | 78,517 | 60 |
| 1948 | 1,811 | 101,008 | 56 |
| 1949 | 1,893 | 106,897 | 56 |
| 1950 | 1,895 | 108,753 | 57 |
| 1951 | 1,698 | 103,978 | 61 |
| 1952 | 1,590 | 108,319 | 68 |
| 1953 | 1,672 | 124,132 | 74 |
| 1954 | 1,801 | 154,133 | 86 |
| 1955 | 1,825 | 176,243 | 97 |
| 1956 | 1,772 | 197,760 | 112 |

Clemens (1961), speaking of the United States west coast albacore fishery noted that, "although the size of the commercial fleet has declined since 1950, well over 1,000 vessels fished for albacore during the 1950 to 1959 seasons inclusive."

### 5.4.2 Selectivity

Brock (1959b) presents typical examples of albacore sizes taken by the different types of gear (Fig. 27).

### 5.4.3 Catches

Japan is by far the world's greatest producer of albacore tuna. Since 1952 the Japanese annual landings of this species have been from two to three times as large as those of the United States, the second largest producing nation (Van Campen, 1960).

Table XVIII, taken from Uchida and Otsu (MS) gives the annual landings of albacore by the various Pacific albacore fisheries for the period 1950-1959.

The annual landings of the Indian Ocean longline fishery for albacore during the period 1952-1957 are presented in Fig. 28.

## 5.5 Fisheries management and regulations

Reproduced below from Clemens (no date) is a brief historical review of regulations concerning albacore in the State of California.

1909 - A commercial fishing license was required for the taking of albacore for profit.

1913 - A sport angling license was required for taking albacore for sport.

1933 - Albacore may be taken at any time of the year. A weight limit in some form has been in effect since 1915 - First weight limit imposed. A brief history follows:

1. 1915-1933 - No albacore less than 6 pounds may be bought, sold, or offered for sale; and no more than 50 pounds may be possessed.

Table XVIII

Annual landings of albacore by the various Pacific albacore fisheries 1950-1959 (in tons) (Uchida and Otsu, MS)

| Year | United States west coast | Japan | | | Hawaii | Chile |
|---|---|---|---|---|---|---|
| | | Winter longline | Spring livebait | South Pacific | | |
| 1950 | 36,207 | 18,423 | 14,179 | 48 | 30 | 271 |
| 1951 | 17,245 | 12,549 | 15,984 | 137 | 28 | 408 |
| 1952 | 26,278 | 19,401 | 46,109 | 79 | 52 | 496 |
| 1953 | 17,417 | 20,522 | 36,301 | 320 | 25 | 735 |
| 1954 | 13,499 | 26,145 | 30,950 | 4,190 | 14 | 316 |
| 1955 | 14,866 | 17,842 | 26,724 | 8,637 | 10 | 709 |
| 1956 | 20,669 | 17,396 | 47,205 | 7,850 | 7 | 892 |
| 1957 | 23,329 | 20,335 | 54,582 | 9,643 | 5 | 485 |
| 1958 | 19,222 | 26,472 | 24,437 | 15,775 | 8 | 142 |
| 1959 | 23,142 | 35,979 | 15,706 | 19,328 | 6 | 13 |

2. 1933-1935 - No albacore weighing less than 9 pounds may be sold.

3. 1955-1957 - No albacore weighing less than 7 pounds may be sold.

4. 1957 to present - No albacore weighing less than 7 pounds may be sold, purchased, or processed.

1935 - A law prohibiting the use of spears to take albacore was passed.

1939 - A bag limit on albacore taken by authority of an angling license was passed. The holder of a commercial fishing license, while on a boat carrying sport fishermen for hire is subject to the same limit.

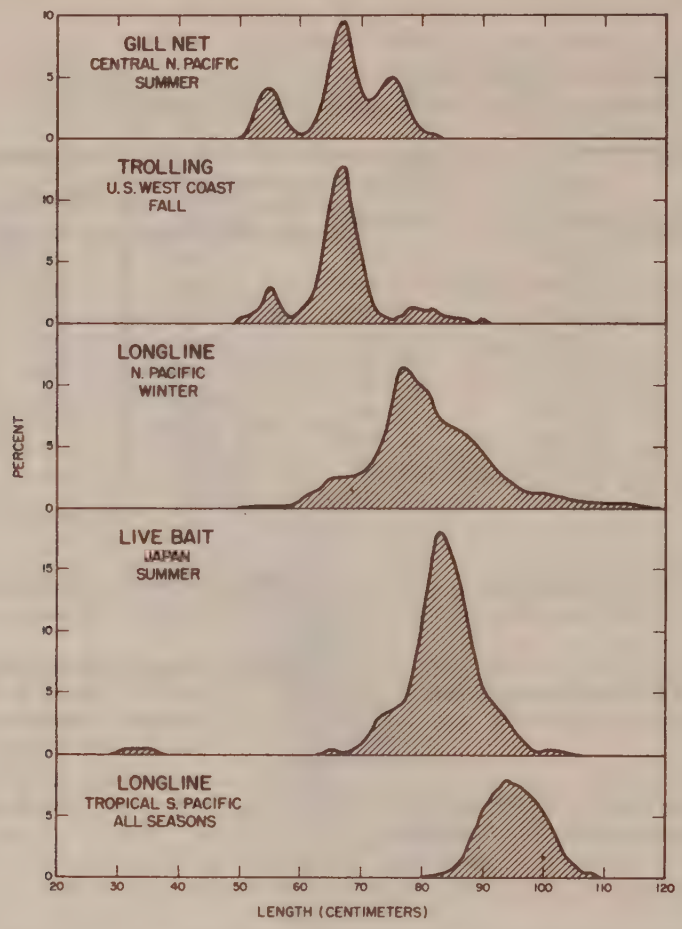


Fig. 27 Albacore sizes taken by various kinds of fishing gear (Brock, 1959b)

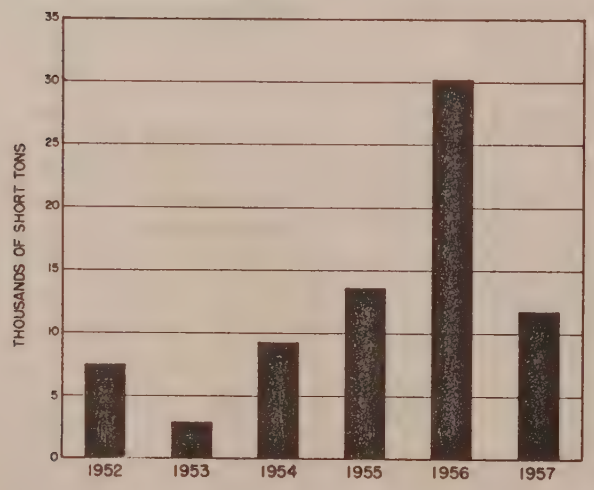


Fig. 28 Annual landings of albacore by the Indian Ocean longline fishery, 1952-57 (Johnson, 1959)

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Experience Paper No. 25

# SCHOOLING BEHAVIOR WITHIN AGGREGATIONS COMPOSED OF YELLOWFIN AND SKIPJACK TUNA

By
HEENY S. H. YUEN
U.S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

## Abstract

Yellowfin and skipjack tuna from aggregations containing both species were studied with respect to size and schooling behavior. A conclusion was drawn that mixed aggregations of yellowfin and skipjack were the result of separate specific schools being attracted together by a common external stimulus, probably food.

## RASSEMBLEMENT EN BANCS DES THONS A NAGEOIRES JAUNES ET DES BONITES A VENTRE RAYE DANS LES CONCENTRATIONS MIXTES DE CES DEUX ESPECES

## Résumé

Des études portant sur la taille des poissons et sur la formation de bancs ont été effectuées sur des thons à nageoires jaunes et des bonites à ventre rayé provenant de rassemblements renfermant ces deux espèces. Il a été conclu que les concentrations mixtes de thons à nageoires jaunes et de bonites à ventre rayé provenaient de l'attraction exercée simultanément sur des bancs distincts par un stimulus externe commun, probablement la présence de nourriture.

## TENDENCIA A LA FORMACION DE CARDUMENES DENTRO DE AGREGACIONES COMPUESTAS DE ATUNES DE ALETA AMARILLA Y BARRILETE

## Extracto

Se estudiaron los atunes de aleta amarilla y barrilete procedentes de agregaciones compuestas por ambas especies con respecto a su tamaño y a su comportamiento gregario. Se dedujo la conclusión de que las agregaciones mixtas de atún de aleta amarilla y barrilete procedían de cardúmenes independientes que habían sido atraídos a unirse por un estímulo externo común, probablemente debido al alimento.

## 1 INTRODUCTION

Occurrences of yellowfin tuna (Neothunnus macropterus) and skipjack tuna (Katsuwonus pelamis) together have been reported and studied by Orange, Schaefer, and Larmie (1957) and Broadhead and Orange (1960). They assumed both species to be in the same school. Recent underwater observations at sea on skipjack and yellowfin feeding together indicate, however, that this assumption may not be true. The objective of this study is to find out whether a simultaneous occurrence of these tunas is a single school of yellowfin and skipjack schooling with each other or a juxtaposition of two monospecific schools.

In order to avoid confusion, I would like to note that the word aggregation is used in this study in its general sense and not as Breder (1959) defines it. It refers to groups of fish without implying any social attraction between group members.

## 2 SOURCES OF DATA

Body length data of skipjack and yellowfin were drawn from Table 7 of Broadhead and Orange (1960) and from records of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu. The former source provided data from 42 yellowfin schools, 64 skipjack schools, and 57 aggregations of mixed species composition. The latter source provided data from 26 aggregations of mixed species composition (Table I). Fourteen of these were encountered in the Tuamotu and Marquesas island groups of French Oceania, 5 in the Hawaiian Islands, 1 in the Line Islands, and 6 in the vicinity of Roca Partida in the Revilla Gigedos Islands.

Observations on the distribution and behavior of skipjack and yellowfin as they fed on live bait thrown from the stern of the Charles H. Gilbert, research ship of the Biological Laboratory, Honolulu, were made on six occasions off Roca Partida during April and May 1960 and once off Hiva Oa in the Marquesas Islands on October 24, 1961. Underwater motion picture records on 16 mm. film made through the viewing facilities of the ship (described by Strasburg and Yuen, 1960) on May 12, 1960, and October 24, 1961, were analyzed for this study. Filming was done in 10-39 sec. sequences throughout the fishing period.

## 3 TREATMENT OF DATA AND RESULTS

### 3.1 Size relationships

Since yellowfin and skipjack tend to school by size (Schaefer, 1948, and Brock, 1954), fish of the two species occurring in the same school would be expected to be similar in size. The mean lengths of yellowfin, however, are longer than the mean lengths of skipjack caught in the same fishing operation by an average of 93 mm., a difference statistically greater than zero ($t = 5.835$, $d.f. = 82$, $p < 0.001$).

On the other hand, yellowfin found with skipjack are on the average smaller than those not found with skipjack (Broadhead and Orange, 1960). This indicates some size selection between species, in view of the fact that skipjack do not attain the size that yellowfin do. A plot of the mean lengths of yellowfin against the mean lengths of skipjack caught at the same time (Fig. 1) clarifies somewhat the size relationships between the two. Small yellowfin (460-490 mm. mean length) were found with small skipjack (340-450 mm. mean length) and larger yellowfin (490-1060 mm. mean length) were found with larger skipjack (470-650 mm. mean length), but no size correlation existed within these groups.

### 3.2 Schooling relationships

On the six occasions off Roca Partida when yellowfin were caught with skipjack, the disorderly succession in which members of both species were landed implied that they were thoroughly mixed. Whenever underwater observations were made of both species together, however, skipjack seemed to be oriented to skipjack and yellowfin to yellowfin, even with the disruption of schooling behavior by the feeding situation. Except for a few occasions the skipjack were concentrated within 2 m. of the surface, while the yellowfin were concentrated below them at about 2.5-3 m. On the excepted occasions, schools of rainbow runner (Elagatis bipinnulatus) preempted the position of the skipjack, whereupon the skipjack descended to the level of the yellowfin. Although the yellowfin remained at the same level, schooling by species was apparent.

Table I

Length data of yellowfin and skipjack
from the same aggregation

| Date | Location | Yellowfin Sample size | Yellowfin Mean length (mm) | Skipjack Sample size | Skipjack Mean length (mm) |
|---|---|---|---|---|---|
| 1/26/57 | Marquesas | 6 | 1059 | 29 | 565 |
| 1/28/57 | " | 25 | 769 | 4 | 542 |
| 2/12/57 | Tuamotu | 9 | 581 | 25 | 475 |
| 2/12/57 | " | 9 | 554 | 21 | 474 |
| 4/27/57 | Hawaii | 3 | 463 | 8 | 347 |
| 4/29/57 | " | 4 | 486 | 12 | 404 |
| 5/6/57 | " | 10 | 478 | 10 | 429 |
| 5/12/57 | " | 6 | 468 | 10 | 449 |
| 5/14/57 | " | 4 | 473 | 7 | 372 |
| 10/27/57 | Marquesas | 6 | 542 | 25 | 529 |
| 1/3/58 | " | 4 | 506 | 25 | 501 |
| 2/27/58 | " | 5 | 746 | 21 | 514 |
| 2/28/58 | " | 14 | 761 | 4 | 486 |
| 3/29/58 | " | 8 | 712 | 30 | 494 |
| 4/18/58 | " | 4 | 581 | 32 | 480 |
| 11/10/58 | Line | 21 | 665 | 6 | 606 |
| 2/2/59 | Tuamotu | 4 | 632 | 17 | 561 |
| 2/23/59 | Marquesas | 25 | 707 | 16 | 524 |
| 3/8/59 | " | 27 | 513 | 23 | 485 |
| 4/16/60 | Revilla Gigedos | 21 | 554 | 20 | 504 |
| 4/16/60 | " | 20 | 522 | 20 | 558 |
| 4/17/60 | " | 15 | 634 | 20 | 575 |
| 4/25/60 | " | 20 | 519 | 20 | 572 |
| 5/12/60 | " | 20 | 491 | 20 | 528 |
| *5/12/60 | " | 6 | 509 | 10 | 565 |
| *10/24/61 | Marquesas | 15 | 846 | 59 | 532 |

* Filmed sequences of these aggregations used in schooling behavior analysis.

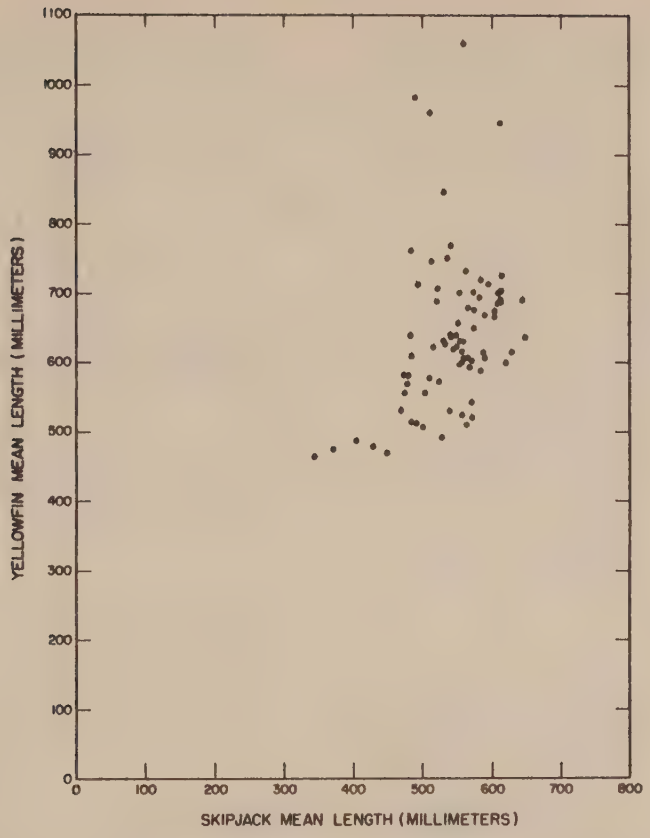


**Fig. 1 Relationship of mean lengths of yellowfin and skipjack of the same aggregation.**

Analysis of the underwater motion pictures provided a more objective examination of schooling behavior. If both species were schooling randomly with no selectivity towards members of their own species, a constant proportion between them would be expected from one film sequence to another. All identifiable fish on film were therefore enumerated and classified by species. A plot of the percentage of skipjack in each film sequence against time (Fig. 2) demonstrates the quantitative variability in the species composition within mixed aggregations. The total number of each species observed in an aggregation was used to calculate an average species proportion (horizontal lines in Fig. 2) for that aggregation. Wide departures from the averages (all expected numbers less than 5 excluded, $X^2 = 216.321$ and 51.875, d.f = 9 and 16, $p < 0.01$) indicate that the members of these species were not uniformly mixed, which in turn suggests that they have a tendency to be with their own.

Interspecific schooling when both species were present is not, however, precluded. To investigate schooling relationships between individuals, all identifiable groups of schooling fish as they appeared on the projection screen were classified by number in the group and species composition. Fish were considered to be schooling if their paths were parallel at any time. The relative positions and distance between fish following parallel paths did not matter as long as they appeared on the screen at the same time and no other fish were between them. In actuality the maximum observed distance between fish considered to be schooling did not exceed 1.5 m.

The percentage of each size group (2 fish, 3 fish, 4 fish, etc.) showing species homogeneity was obtained for each film sequence. The observed percentages were compared with curves of expected percentages of homogeneous groups from populations of varying proportions of two species. Comparisons for groups of two, three and four are represented in Fig. 3.

Points describing the curves of Fig. 3 are percent expressions of probabilities calculated from the following equation:

$$p = \frac{C_s^g}{C_{(s+y)}^g} + \frac{C_y^g}{C_{(s+y)}^g}$$

where:

$p$ is the probability of obtaining a homogeneous group (either yellowfin or skipjack) of size $g$ from all combinations of size $g$ possible from a population of $s$ skipjack and $y$ yellowfin;

$C_s^g$ is the number of ways groups of $g$ skipjack can be formed from $s$ skipjack;

$C_y^g$ is the number of ways groups of $g$ yellowfin can be formed from $y$ yellowfin;

$C_{(s+y)}^g$ is the number of ways groups of $g$ members can be formed from a population of $s + y$ individuals.

The value $p$ increases towards a limit as $s + y$ approaches infinity. The curves of Fig. 3 represent the limit values of $p$ in percent plotted against the percent equivalent of $\frac{s}{s+y}$.

The points of Fig. 3 are observed values, each point representing a film sequence. The position of each point was calculated using only those fish found in the group size concerned. For example, one sequence contained 14 pairs. Of the 28 fish involved in pairs, 8 were skipjack and 20 yellowfin giving $\frac{8}{28}$ or 28.6 percent skipjack. Nine pairs were solely yellowfin and 3 solely skipjack so that 12 pairs out of 14 or 85.7 percent were homogeneous. The number beside each point is the number of groups represented by the point.

Points above the calculated curves mean that more homogeneous groups were observed than expected, which indicates that fish tend to select members of their own species with which to school. Conversely, points below the curves mean that less homogeneous groups were observed than expected, which indicates a preference for members of the other species for schooling companions. The points above and below the curves were counted (Fig. 4) and a chi-square test applied to the pooled data. The expected number was taken as half the total number of points, since the points would be expected to be distributed equally above and below the curves if the fish showed no species selectivity in schooling. The highly significant chi-square value of 18.689 ($\chi^2$ at $P_{.01}$ is 6.635) resulted from an excess in the direction of homogeneous groups.

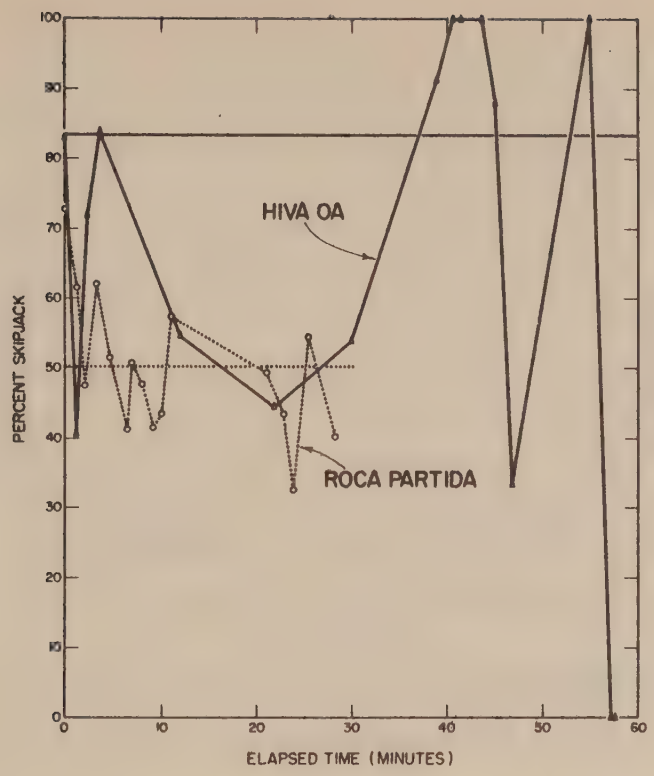


**Fig. 2 Changing species proportions within mixed aggregations with time.**

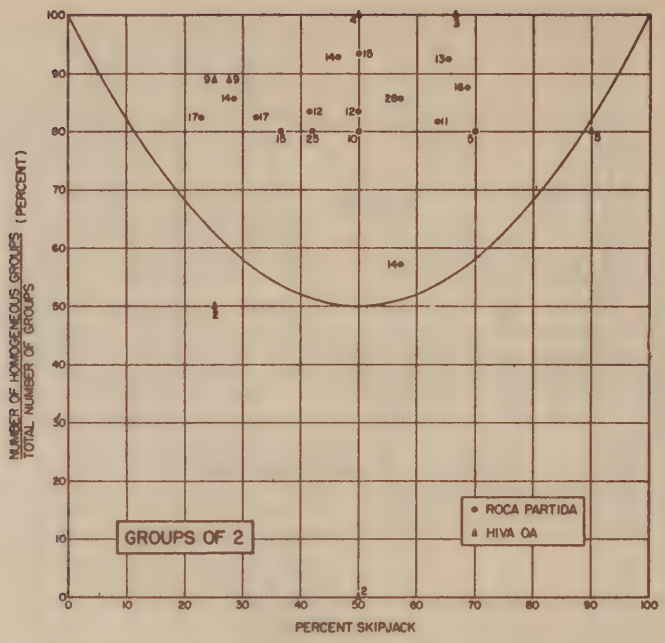


Fig. 3a Comparison of observed percentage of homogeneous groups in species mixtures of different proportions with that expected by chance.

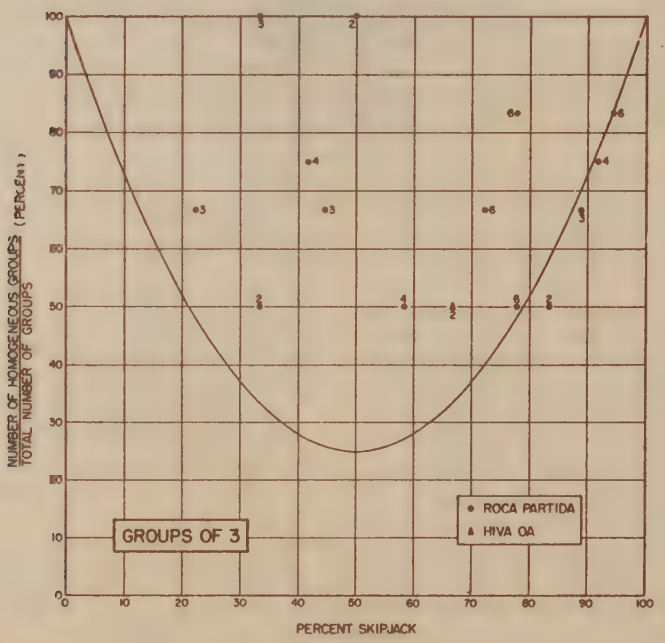


Fig. 3b Comparison of observed percentage of homogeneous groups in species mixtures of different proportions with that expected by chance.

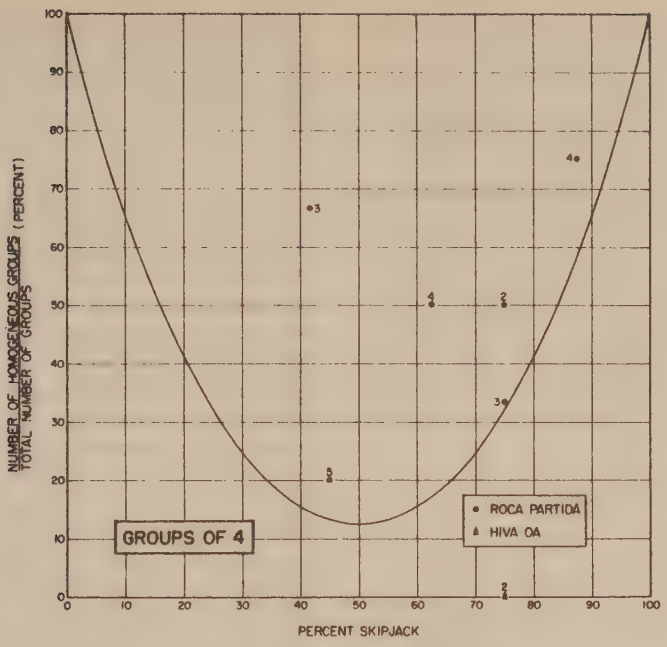


Fig. 3c Comparison of observed percentage of homogeneous groups in species mixtures of different proportions with that expected by chance.

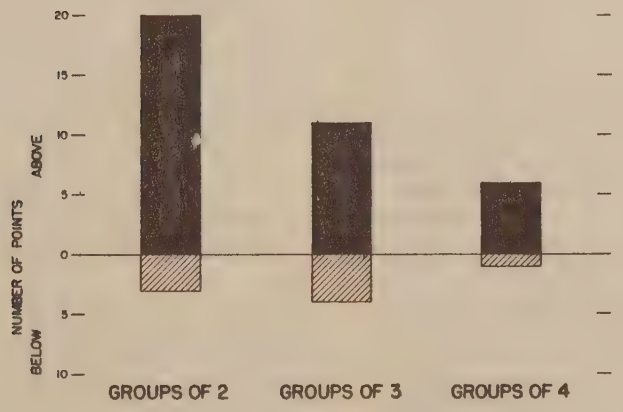


Fig. 4 Distribution of observed percentages of homogeneous groups above and below those expected by chance.

The chi-square value is a conservative one for the following reasons. (1) The expected curves of Fig. 3 are based on the limits of $\underline{p}$, which are maximum values of $\underline{p}$. Had $\underline{p}$ been based on numbers of s + y comparable to the observed numbers, more of the points would have fallen above the curves. (2) More than one fish in pursuit of the same prey sometimes followed parallel paths. These fish were not distinguished from those orienting with each other. Including them in the data introduced an error biased towards heterogeneous groups, because fish of the same species pursuing the same prey were more likely to be schooling together before sighting the prey than fish not of the same species pursuing the same prey.

## 4 CONCLUSION AND DISCUSSION

The results lead to the conclusion that yellowfin and skipjack tuna prefer to school with members of their own species. Occurrences of both species together, therefore, are most likely congregations of separate schools of yellowfin and skipjack responding to some common external stimulus.

It appears most likely that the stimulus which brings schools of yellowfin and skipjack together is a common interest in similar foods. This hypothesis would be strengthened if it could be shown that aggregations of the two species are more frequently actively feeding than are "pure schools" of either species alone. In fact, certain differences between the catches of pole-and-line fishing boats and purse-seiners (Broadhead and Orange, 1960) provide evidence that this is the case. The pole-and-line fishery, which depends on fish in the act of feeding for its effectiveness, takes a higher percentage of its total catch from mixed aggregations than does the purse-seine fishery in which active feeding is not a prerequisite to capture. The hypothesis is further supported by the results of studies for the stomach contents of the two species, for lists of yellowfin food items (Reintjes and King, 1953) and skipjack food items (Yuen, 1959) show many similarities.

The assumption that the coincidental pursuit of the same prey is what brings schools of skipjack and yellowfin together also points to an explanation of the tendency for large skipjack to be found with large yellowfin and small skipjack with small yellowfin in mixed aggregations, a tendency which taken by itself would appear to indicate true interspecific schooling. It has been shown that the diet of yellowfin changes to some extent as the fish grow and become capable of ingesting larger organisms (Reintjes and King, 1953), and the same thing might reasonably be expected to be true of skipjack. Thus, the apparent size association in "mixed schools" may be ascribable to a parallel development of food habits with growth in the two species, such that large yellowfin and large skipjack will tend to converge on the same prey, while small individuals of both species will pursue other, smaller feed. Again, there is evidence to support this idea in the differences between purse-seine and pole-and-line catches. The difference in size of yellowfin taken from monospecific schools and from mixed aggregations is greater in the purse-seine fishery than in the pole-and-line fishery. This indicates that the large yellowfin taken from monospecific schools by purse seines have developed food habits which lessen the likelihood of their converging on a common prey in company with the smaller tuna species.

## 5 SUMMARY

The schooling behavior of skipjack and yellowfin tuna occurring together was studied by analyzing data on body lengths from 83 composite aggregations of these species and motion picture records of 2 of these aggregations. The results show that :

(1) There is a mean difference of 93 mm between the mean lengths of yellowfin and skipjack found in the same aggregation.

(2) Small yellowfin (460-490 mm mean length) were found with small skipjack (340-450 mm mean length) and larger yellowfin (490-1060 mm mean length) with larger skipjack (470-650 mm mean length), but no interspecific correlation in lengths existed within each group.

(3) Skipjack and yellowfin within an aggregation were not uniformly mixed.

(4) More monospecific groups of schooling individuals were observed than would have been expected if there were no species selection in schooling.

A conclusion was made that skipjack and yellowfin in composite aggregations were from separate specific schools attracted to some common external stimulus. Food was hypothesized as the common stimulus.

## 6 ACKNOWLEDGMENTS

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# EFFECT OF SALINITY ON GROWTH OF POSTLARVAL PENAEID SHRIMP

ZOULA P. ZEIN-ELDIN

*Bureau of Commercial Fisheries, Galveston, Texas*

# EFFECT OF SALINITY ON GROWTH OF POSTLARVAL PENAEID SHRIMP[1]

ZOULA P. ZEIN-ELDIN

*Bureau of Commercial Fisheries, Galveston, Texas*

The general life-history pattern of commercially important penaeid shrimps of the northern Gulf of Mexico has been known for some years (Pearson, 1939; Weymouth, Lindner and Anderson, 1933; Burkenroad, 1939). That the adults spawn offshore, the young migrate shoreward to the estuaries for a period of rapid growth, and then return to the offshore areas is generally accepted. However, neither the stimulus for the migrations nor the factors controlling the period of time spent in the estuaries are well understood. Several explanations for this behavior have been advanced. Some authors indicate that salinity *per se* is of prime importance. For example, Pearse and Gunter (1957) state (p. 147): "The young of many animals, usually thought of as marine, require areas of low salinity for nursery grounds. The distribution and abundance of the blue crab and the commercial shrimp (*Penaeus setiferus*) on the South Atlantic and Gulf coasts are dependent on the presence of estuarine areas. The shrimp spawn in oceanic salinities; the early stages apparently require oceanic water, but the older larvae must reach bay waters or perish. The young shrimp grow up in the low-salinity bays and return to the sea." Other authors, including Lindner and Anderson (1956) and Hoese (1960), have felt salinity to be of less importance. Broad (1962, p. 1), referring to penaeids, remarks: "Thus, while almost every investigator during the last thirty years has considered salinity in relation to shrimp distribution . . . it is still not possible to state what effect salinity may have, for example, on the growth of shrimps." The following experiments were designed to evaluate the effects of salinity upon the growth of postlarvae of the white shrimp, *Penaeus setiferus*, and either the brown shrimp, *P. aztecus*, or the pink shrimp, *P. duorarum*.

## Materials and Methods

Two series of growth experiments were conducted, the methods being generally the same in each. Large numbers of postlarval shrimp were seined from nearby surf zones for use as experimental material in both series. Prior to transfer into experimental vessels, the small shrimp were held for 24 hours under laboratory conditions in quantities of the same water in which they were caught, or in water of the same salinity. One hundred postlarval penaeids were placed in each experimental tank; the salinity of the medium at this time was identical to that at which the animals had been caught. Salinity was decreased stepwise by removing sea water and replacing it with an equal volume of distilled water. Salinity was increased

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similarly using concentrated sea water in place of distilled water. Stepwise salinity changes required 48 hours in the first series (GS-1) and 120 hours in the second (GS-2) (Table I).

The experimental vessels consisted of 20-gallon glass aquaria fitted with "Eureka" inside plastic filters which filtered and aerated the water. The filters were covered with ground oyster shell topped with fine beach sand, the combination serving both as a filter bed and as a substrate for the animals. Both shell and sand were washed and heat-sterilized before use. At the start, 40 l. of sea water were added to each aquarium. The initial salinity of the water was 25‰ (parts per thousand) in series GS-1 and 39‰ in series GS-2. Salinity was determined semi-weekly using a hydrometer.

A thin (2-mil) polyethylene film was placed in contact with the surface of the water in the experimental tanks to reduce evaporation and to prevent escape of

TABLE I

*Schedule of salinity changes*

| Date | Elapsed time (hr.) | Initial salinity (‰) | Desired salinity | | | | |
|---|---|---|---|---|---|---|---|
| | | | 2‰ | 5‰ | 10‰ | 25‰ | 40‰ |
| Series GS-1: | | | | | | | |
| 4/12/62 | 2 | 25 | — | 20 | 20 | No change | 33 |
| | 7 | | — | 15 | 15 | No change | 38 |
| 4/13/62 | 26 | | — | 10 | 10 | No change | 40 |
| | 31 | | — | 5 | 10 | No change | 40 |
| Series GS-2: | | | | | | | |
| 7/26/62 | 3 | 39 | 35 | 35 | 35 | 35 | 40 |
| | 8 | | 30 | 30 | 30 | 30 | 40 |
| 7/27/62 | 24 | | 25 | 25 | 25 | 25 | 40 |
| | 31 | | 21 | 21 | 21 | | |
| 7/28/62 | 48 | | 17 | 17 | 17 | | |
| | 55 | | 13 | 13 | 13 | | |
| 7/29/62 | 72 | | 10 | 10 | 10 | | |
| | 63 | | 7.5 | 7.5 | | | |
| 7/30/62 | 96 | | 5.0 | 5.0 | | | |
| | 104 | | 2.0 | | | | |

the postlarvae. During preliminary work in the absence of the film, as many as 20 postlarvae had been found trapped on the side of a tank in a single day. That this method was successful in reducing such losses is indicated by the 100% survival noted in some sections of the experimental series.

The schedule of salinity changes in the two series is given in Table I. Salinity reduction required more time during the second series because of the higher initial salinity. In neither series were deaths noted during the acclimation period.

During both series of experiments the laboratory temperature was maintained at 23 to 25° C. while the water temperature ranged from 24.5 to 26° C. Each aquarium was continuously illuminated by two 14-watt daylight fluorescent bulbs.

It should be noted that the animals in the two series were caught at different water temperatures. Animals in series GS-1 came from water of 23° C. whereas those in GS-2 came from water of 30° C.

Initial measurements in each experiment were obtained from samples of 10 postlarval shrimp withdrawn from the source population. After excess water was removed, the length of each specimen was measured to the nearest 0.5 mm. (distance from tip of rostrum to end of telson), and its weight determined to the nearest 0.1 mg. on a Mettler H15 analytical balance. All individuals were preserved for later study. Subsequent samples from each experimental tank were similarly treated after being withdrawn at approximately 5-day intervals. Both the largest and the smallest specimens in each tank at each sampling period were

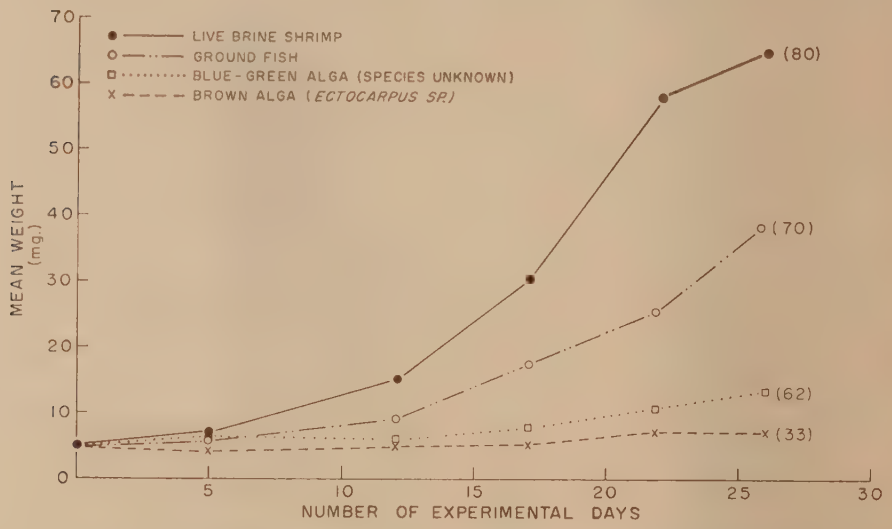


FIGURE 1. Growth of postlarval penaeids fed various diets. Figures in parentheses indicate percent survival at termination of experiment.

included in order to determine size ranges; the remaining eight were selected at random. After approximately 30 days, the surviving animals in each tank were weighed individually and preserved.

Preliminary experiments which were of similar design and carried out at 25‰ had indicated that a live food was to be preferred. Figure 1 not only indicates that growth was substantially better among the postlarvae fed brine shrimp, *Artemia*, nauplii, but that survival was also greater. As Williams (1959) has previously noted in the brown shrimp, those animals fed algae always had full guts and deposited deep green or brown feces, but neither their growth nor their survival approached the levels attained by animals fed the brine shrimp diet. In addition to a slightly poorer growth rate among animals fed ground fish or shrimp, there was a practical problem caused by fouling of the water with excess food. For

these reasons, brine shrimp nauplii constituted the sole dietary supply in the salinity experiments described. Laboratory cultures of brine shrimp were filtered and washed before use in order to avoid salinity changes in the experimental tanks caused by the addition of saline (brine shrimp) culture medium. Equal amounts of brine shrimp were given to postlarvae in all tanks. The volume and number of feedings per day were increased during the experiment in order to maintain an excess of food in the tanks.

Although all the shrimp in series GS-1 (April, 1962) were tentatively identified as grooved shrimp, *i.e.*, brown shrimp or pink shrimp, those obtained for GS-2 (July, 1962) apparently included both "grooved" and white shrimp in an approximate ratio of five grooved to one white. Tentative species identification was made following Williams (1959), with early postlarvae (less than 10 mm. rostrum-telson length) being differentiated on the basis of ratio of distance from rostrum to eye and distance from third pereiopod to eye, and specimens longer than 17 mm. on the basis of the presence or absence of a groove. Conflicting evidence is available concerning identification at lengths between 10 and 17 mm. Thus, identification must be regarded as tentative, although some confirmation of species ratio was available from the animals surviving for 30 days.

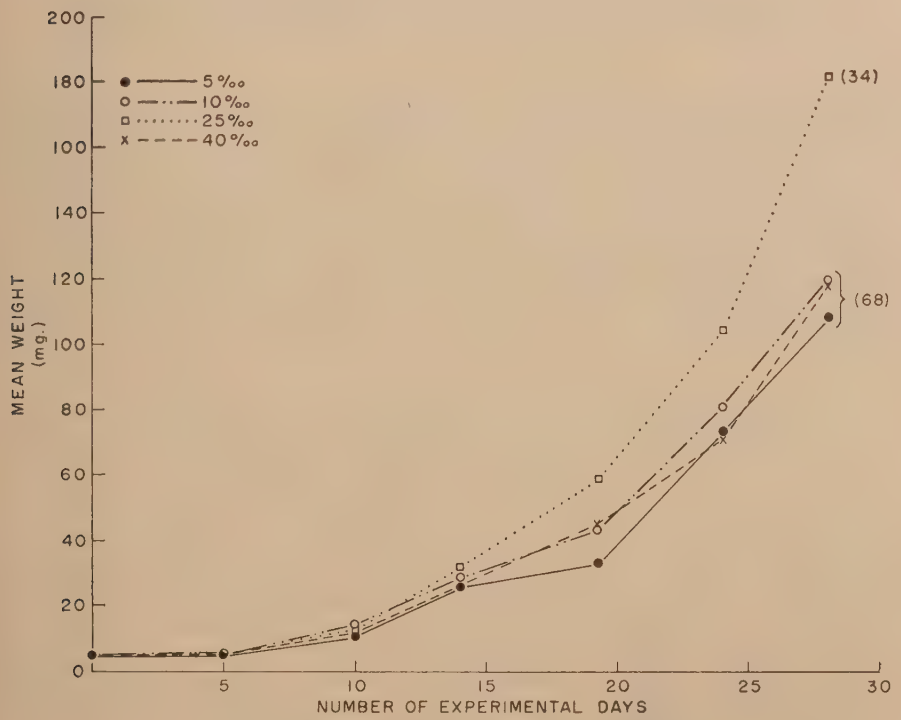


FIGURE 2. Growth of postlarval penaeids at various salinity levels in series GS-1. Figures in parentheses indicate percent survival at termination of experiment.

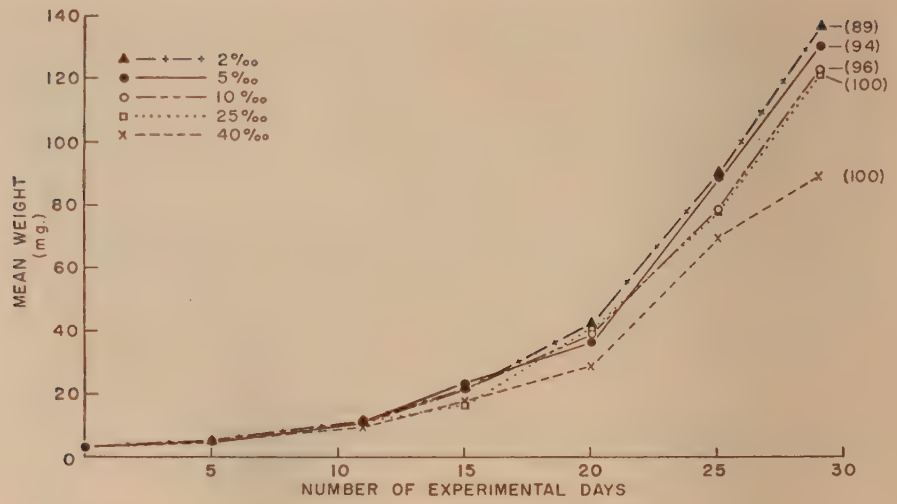


FIGURE 3. Growth of postlarval penaeids at various salinity levels in series GS-2. Figures in parentheses indicate percent survival at termination of experiment.

As indicated in Figures 2 and 3, growth of the postlarvae occurred at all salinity levels tested in both series of experiments. Growth has been expressed as total weight in mg. (Tables II and III) rather than as total length since, as shown in Figure 4 (which is based on animals measured during these experiments), weight increases more rapidly than length and is therefore less influenced by relative measurement error. Thus, in the first 5 days, weight increased by about 50% while total length increased only 15%. In each subsequent 5-day period weight generally doubled while length was increasing only 25%. For this reason weight has been used here as a more sensitive indicator of growth than total length.

TABLE II

*Mean animal weight (in mg.) at each salinity level in experimental series GS-1. Values are based on weights of 10 animals. Figures in parentheses indicate one standard error*

| Elapsed days | Salinity level | | | |
|---|---|---|---|---|
| | 5‰ | 10‰ | 25‰ | 40‰ |
| 0 | — | — | 4.5 (0.2) | — |
| 5 | 5.7 (0.3) | 5.4 (0.6) | 6.6 (0.4) | 6.2 (0.4) |
| 10 | 14.1 (1.4) | 10.9 (0.9) | 13.0 (1.5) | 11.9 (0.8) |
| 14 | 29.1 (3.3) | 26.2 (3.6) | 32.6 (4.4) | 26.3 (4.2) |
| 19 | 43.8 (5.0) | 32.7 (6.0) | 58.9 (10.6) | 45.4 (10.4) |
| 24 | 81.4 (9.2) | 72.9 (8.6) | 104.7 (14.2) | 71.3 (6.8) |
| 28 | 119.6 (13.6) | 108.7 (18.6) | 182.0 (18.8) | 118.0 (19.1) |

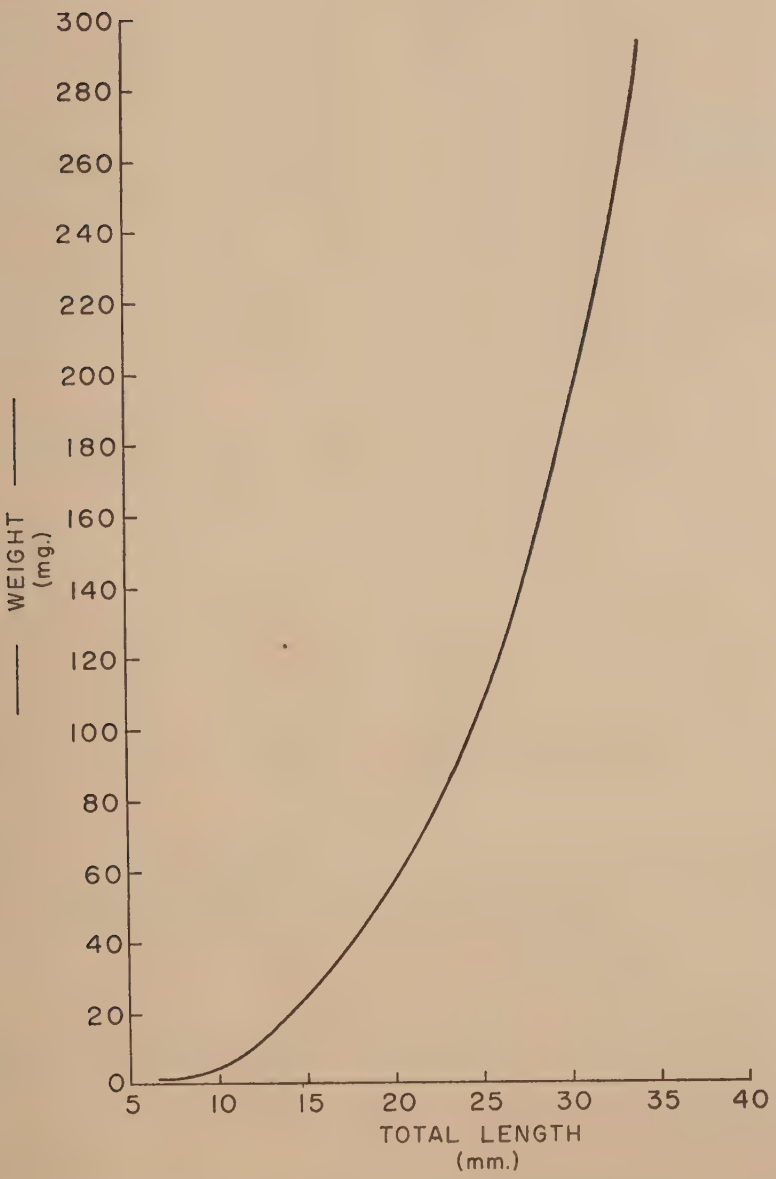


FIGURE 4. Weight-length relationship in postlarval penaeids.

Although growth appeared to be much greater in the first series at the 25‰ salinity level, it must be noted that the per cent survival was considerably less than that at the other salinities (Fig. 2). Comparison by *t* tests of mean weight increments at 25‰ *vs.* those at other salinity levels revealed that growth at the former level was greater throughout the series than at any other level tested. The increased growth rate may be related to the fact that more food was available for each surviving animal as a result of the increased mortality, or it may be a simple reflection of the decreased population density. There was no apparent reason for the greater mortality in this tank, and, indeed, as noted in earlier feeding experiments (all conducted at 25‰) as well as in the later salinity series GS-2, both growth and survival were rated as excellent at this salinity. No significant difference between other pairs of means in this series could be detected.

In the second series of experiments (GS-2), survival was considerably better than that occurring during the first series. All test animals survived at both 40‰ and at 25‰, and survival in no case was less than 84%. This better survival may

TABLE III

*Mean animal weight (in mg.) at each salinity level in experimental series GS-2. Values are based on weights of 10 animals. Figures in parentheses indicate one standard error*

| Elapsed days | Salinity level | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2‰ | | 5‰ | | 10‰ | | 25‰ | | 40‰ | |
| 0 | — | | — | | — | | 2.9 | (0.2) | — | |
| 5 | 4.8 | (0.2) | 4.8 | (0.2) | 4.3 | (0.1) | 4.3 | (0.4) | 4.3 | (0.4) |
| 11 | 11.1 | (1.6) | 10.8 | (1.2) | 11.0 | (1.0) | 9.9 | (1.2) | 9.9 | (1.2) |
| 15 | 21.2 | (2.7) | 23.1 | (4.0) | 22.6 | (3.5) | 16.5 | (2.0) | 17.8 | (2.9) |
| 20 | 42.6 | (7.3) | 36.5 | (9.0) | 36.9 | (6.3) | 40.3 | (7.1) | 19.1 | (2.3) |
| 25 | 90.2 | (21.2) | 88.9 | (24.4) | 78.6 | (17.0) | 77.3 | (12.2) | 69.6 | (10.6) |
| 29 | 140.9 | (23.3) | 147.4 | (27.7) | 135.0 | (31.2) | 138.4 | (22.2) | 94.7 | (10.4) |

have been due to a difference in the medium (sea water for GS-2 was obtained directly from the surf zone whereas that for GS-1 came from a large recirculating sea-water system), or to better feeding. It is significant that 100% survival occurred in the two highest salinity levels and that considerable growth occurred even at 40‰. This would indicate that postlarval penaeids are not only able to withstand such high salinity for a fairly long period of time, but can grow at a rate nearly as great as that attained at presumably more "normal" levels.

It is interesting to note that the rate of growth varied considerably among individuals within the same tank, regardless of the salinity. Specimens in initial samples ranged from 3.6 to 5.6 mg. and from 10.0 to 11.0 mm. in GS-1, whereas animals in GS-2 ranged from 1.3 to 3.8 mg. and from 6.5 to 10.0 mm. However, at 29 days, when experiment GS-2 (25‰) terminated, weights varied between 39.5 and 305.4 mg. and lengths between 17.0 and 36.5 mm. Such variation was noted during both series of experiments. In each, growth exceeded that recorded by Pearson (1939) for either white or "brown" shrimp postlarvae in laboratory aquaria, but was probably less than that occurring under natural conditions.

## Discussion

Although salinity has long been considered a major factor in the ecology of commercial penaeid shrimps, few data have been available either to substantiate or negate claims that low salinity is a requirement for the growth of postlarval shrimp. That postlarval shrimp are found in low salinity water is an undisputed fact, but the influence of salinity *per se* on this distribution has not been determined. Lindner and Anderson (1956) reported that the size of young shrimp was correlated more with locality than salinity and concluded that salinity within broad ranges was not important. Hoese (1960) states (p. 593) : "It would seem that within certain areas, at least, salinity in broad ranges is inconsequential to young shrimp. All the habitats where juveniles have been found could offer protection from predators. . . . It appears that juvenile *P. setiferus* and *P. aztecus* can populate areas of relatively high salinity if other environmental factors are ideal." Gunter, too, has modified his stand concerning the importance of salinity. He states (1961, p. 599) : "Small shrimp are not killed or precluded by high salinity as if it were poison; they simply do not do well in it, for reasons unknown." Nevertheless, he mentions finding 115 white shrimp ranging in length from 15–66 mm. in the Laguna Madre at a salinity of 41.3‰. Johnson and Fielding (1956), in attempts to rear shrimp in ponds, noted that white shrimp could be raised at salinity levels of 18.5 and 34‰, and Williams (1960), in experiments concerning the osmotic relationships of brown and pink shrimp, found that temperature apparently had far more effect upon survival than did salinity. The experiments presented here indicate that under the conditions tested (restricted temperature and diet), postlarval shrimp can both survive and grow over a wide range of salinities. Thus, it would appear that salinity tolerances *per se* may not play a direct role in the growth and survival of postlarval and juvenile shrimp in the estuarine environment.

It may be tentatively suggested that food requirements may be of more importance than the purely physical factors. Some indication of this food requirement was noted during these experiments, for it was, in fact, the inability to provide food in sufficient quantity which terminated the experiments after only a month. The relationship of growth to utilization of food is now being studied in an effort to obtain an estimate of the food required to produce a given weight of shrimp. Further studies will test the effect of population density upon growth. Future work will also include experiments concerning the interrelation of temperature and salinity and their combined effect upon the growth of postlarval shrimp.

The method of preventing postlarval escape by use of polyethylene film was designed by Dr. David V. Aldrich. His help and the assistance of Mr. Don S. Godwin and Mr. Roger M. Friedberg is gratefully acknowledged.

## Summary

1. The effect of salinity on the growth and survival of postlarvae of white, *Penaeus setiferus,* and grooved shrimp, *P. aztecus* or *P. duorarum,* has been studied in the laboratory.

2. Growth rate did not differ significantly among shrimp held at 2, 5, 10, 25, or 40‰.

3. Survival was generally excellent at all salinity levels tested, including 40‰.

4. The results suggest that salinity *per se* does not limit growth of young shrimp.

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# CATCH LOCALITY, FISHING EFFORT, AND LENGTH-FREQUENCY DATA FOR ALBACORE TUNA LANDED IN OREGON, 1951-60

Robert J. Ayers
and
James M. Meehan

INVESTIGATIONAL REPORT NO. 2

FISH COMMISSION OF OREGON
CLACKAMAS, OREGON

AUGUST 1963

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# CATCH LOCALITY, FISHING EFFORT, AND LENGTH-FREQUENCY DATA FOR ALBACORE TUNA LANDED IN OREGON, 1951-60

## INTRODUCTION

Major fluctuations in the availability of albacore tuna (Thunnus alalunga) to commercial fishermen operating in the northeastern Pacific Ocean occur annually and seasonally. These fluctuations in availability may possibly be the result of variations in the environment. The scientists of several agencies are examining oceanographic and meteorological data collected from various sources to determine the nature and magnitude of the changes that have taken place in the oceanic environment in the eastern Pacific. By comparing environmental changes with variations in albacore fishing success it may be determined whether these changes are responsible for fluctuations in seasonal appearance, distribution, and relative abundance of albacore. This is a compilation of catch and fishing-effort data for Oregon albacore landings which may be compared with the information compiled on the oceanic environment. The collection of these data was carried out as a routine part of the state research program on marine fisheries. The compilation and publication was accomplished with the financial assistance of the U. S. Bureau of Commercial Fisheries, California area.

## SOURCES OF INFORMATION

The catch locality and fishing-effort data presented here were collected by interviewing fishermen engaged in the albacore fishery. Boat logs were copied or standard questions asked concerning the locality of catch and fishing effort during the unloading operation. Samples of the fish were then measured to determine the size composition. Table 1 shows the intensity of sampling for the years 1951-60. The total pounds of fish landed, pounds landed for which interviews were obtained, and the per cent of the total catch for which interviews were obtained are shown for each month. Table 2 gives the annual

Oregon albacore landings by month and port as compiled from the Oregon Fish Commission IBM poundage records.

## METHODS

The statistical areas used in this report are a modification of the system used by the Inter-American Tropical Tuna Commission (Schaefer, 1953) and California Department of Fish and Game (Clemens, 1955). The northeastern Pacific is divided into blocks by one-degree divisions of latitude and longitude. The blocks are designated by the latitude and longitude of the southeast corner of each block.

Due to differences in fishing habits, landings at the various Oregon ports could not be assigned from the results obtained from one or two ports (such as using Astoria and/or Newport information to assign areas of catch to Coos Bay landings). For this reason assignment could not be made for any port during a month when no sampling occurred. This accounts for the differences between the total pounds landed in Table 1 and the totals for Tables 4-13. Table 3 shows the percentage of the total catch that could be assigned to the one-degree blocks.

Catch locality and fishing effort data were taken directly from fisherman interviews. Information collected during the interviews included: date of landing, area fished each day, number of albacore caught each day, number of days fished, and total pounds landed.

The area fished each day was usually in the form of several loran bearings and these bearings were assigned to the one-degree area in which they occurred. The total pounds caught per month were then prorated to one-degree areas from the interview assignments. Total numbers were calculated for one-degree areas by dividing the total pounds assigned by the average weight per fish per month per one-degree area. The average weight figure was achieved by dividing interviewed pounds by interviewed numbers. Days fished per area were calculated in a similar manner using total and sampled pounds and the number of days fished

per area from the interviews.

All figures and tables in this report except those in Table 2 are based on month of catch rather than month of landing.

## CATCH LOCALITIES

In Tables 4-13 are listed the calculated total catch of albacore by one-degree blocks by month of catch, port of landing, and method of fishing for the years 1951-60. Five entries are made for each square in which fishing was conducted: the calculated total number of fish caught; the calculated total pounds of fish caught; the calculated total number of days fished; and, in parentheses, the average number and pounds caught per day. Figures 1-34 are pictorial presentations of Tables 4-13 and include only those pounds for which assignment has been made.

The major portion of albacore landed in Oregon are caught by trolling lures at or near the surface (jig boats). However, substantial landings were made by boats using live bait and the pole and line method (bait boats) during the 1952, 1953, and 1958 seasons.

## SIZE COMPOSITION

Length-frequency samples to measure the size composition of the catches were usually taken in conjunction with interviewed sampling. Fork length was measured to the nearest lower centimeter with large calipers. Tables 14-78 list the length-frequency data collected by month and port for the years 1939-60. The samples have been assigned to one-degree blocks of catch when this information was known. Other catches have been designated as being caught north or south of Point Delgada, California ($40^{\circ}$ north latitude) when the exact area of catch was unknown. Tables 52 and 61 contain length frequencies taken at sea on tagging cruises. In most instances the size compositions at all Oregon ports were very similar. Exceptions to this occurred when landings were small and the fish were caught primarily off the central California coast. Table 79 lists

the length-frequency distributions in per cent by month and year, grouping catches and landings from all areas and ports. Figures 35 through 52 are graphical presentations of these data.

The length-frequency distributions show the annual appearance of 2, 3, or 4 size groups in Oregon landings. The modal lengths for the 10 seasons shown are placed with very nearly the same intervals--at about 55, 65, 76, and 85 cm. The most abundant group taken during the fishing seasons of 1950-52 and 1954-60 was that with the modal length of 65 cm. In 1953, fish of the 55-cm group predominated. Usually two of the size groups are of importance in the landings. This condition tends to contribute to sharp fluctuations in catches, since if either or both of the dominate groups are poorly represented in the catches, no other size groups are abundant enough to maintain a relatively stable catch.

## SEASONAL DISTRIBUTION OF CATCHES

The albacore fishery off the Oregon coast normally starts during July and continues through September. During some years good catches are made in October but usually fish landed in October and November are caught off the California coast. The majority of albacore landed in Oregon since 1955 have been caught during August and September between 35 and 48° north latitude and east of 128° west longitude. From 1951 to 1955 catches were made in the same area but occurred during September and October.

During the 1951 season the fishery was centered off the Columbia River during July and August. A second center developed off Cape Mendocino in August. During September both centers moved south about 125 miles. Catches continued off the southern Oregon coast until late October.

Only a few fish were caught off the northern Oregon coast in July 1952. Catches did not improve greatly during August and most of the fish landed were taken between southern Oregon and Cape Mendocino. In September catches improved although the area of catch remained substantially the same as in earlier months.

Virtually no tuna were taken off the Oregon coast during the 1953, 1954, and 1955 seasons. Fish landed in Oregon during these years were taken from San Francisco south to Baja California.

Albacore were again taken off the Oregon coast during the 1956 season. Good catches were made from the Columbia River south to Coos Bay during August and September.

Moderate catches were made in July 1957 and were well distributed from Cape Flattery to just south of Cape Blanco. Fishing improved during August and extended from central Vancouver Island to northern California. A few scattered catches were also made as far south as Baja California. Good fishing continued during September but the center of activity moved steadily southward. Good catches were made off the California-Oregon border during October.

Albacore fishing improved considerably during the 1958 season. A strong fishery developed in July centering off the central Oregon coast and a moderate secondary center developed off the central California coast. During August success in the southern area diminished while the northern center improved and extended north to Destruction Island. The best catches during this period came from Grays Harbor to Coos Bay. Fishing success was reduced during September and moved southward about 75 miles. Catches dropped sharply during October but some fish were taken off Tillamook.

Albacore landings during the 1959 season increased approximately 8% over the excellent 1958 landings. The 1959 total landings were the highest since 1945. A fishery developed rapidly during July with substantial catches made off the Oregon and southern Washington coasts. Smaller catches were made off central California. Fishing continued to improve in August and excellent catches were made in the area from Destruction Island to Cape Mendocino. The catch in September was approximately half of the August catch with no significant change in fishing area. Fishing success dropped sharply in October with only small catches being made in the area from Newport to Tillamook.

The 1960 season started rather slowly. Some fish were taken off the Columbia River and scattered catches were made south of Cape Mendocino. A good fishery developed during August from Destruction Island to Newport and in the San Francisco-Monterey Bay region. Catches remained steady off Oregon during September but the fishery off central California increased substantially. October catches were confined to the Cape Mendocino-San Francisco area.

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Schaefer, M. B. 1953. Report on the investigations of the Inter-American Tropical Tuna Commission during the year 1952. Inter-Am. Tropical Tuna Comm. Ann. Rept. for 1952: 14-35.

Table 1
Sampling Intensity for the Oregon Albacore Fishery, 1951-60

| Assigned Month | Total Catch (Pounds) | Pounds Sampled | Per Cent of Catch Sampled |
|---|---|---|---|
| 1951: | | | |
| July | 163,000 | 26,474 | 16.2 |
| August | 241,000 | 17,283 | 7.2 |
| September | 1,678,800 | 68,482 | 4.1 |
| October | 732,200 | 0 | 0 |
| November | 101,600 | 6,610 | 6.5 |
| TOTAL | 2,916,600 | 118,849 | 4.1 |
| 1952: | | | |
| July | 14,000 | 5,114 | 36.5 |
| August | 178,900 | 45,782 | 25.6 |
| September | 1,264,200 | 485,097 | 38.4 |
| October | 819,200 | 117,489 | 14.3 |
| November | 256,500 | 0 | 0 |
| December | 52,600 | 0 | 0 |
| TOTAL | 2,585,400 | 653,482 | 25.3 |
| 1953: | | | |
| August | 54,300 | 32,045 | 59.0 |
| September | 624,200 | 73,749 | 11.8 |
| October | 96,200 | 21,604 | 22.5 |
| November | 1,000 | 0 | 0 |
| TOTAL | 775,700 | 127,398 | 16.4 |
| 1954: | | | |
| August | 14,300 | 3,337 | 23.3 |
| September | 274,000 | 44,591 | 16.3 |
| October | 171,000 | 25,901 | 15.1 |
| November | 10,200 | 0 | 0 |
| TOTAL | 469,500 | 73,829 | 15.7 |

Table 1 (Continued)

| Assigned Month | Total Catch (Pounds) | Pounds Sampled | Per Cent of Catch Sampled |
|---|---|---|---|
| 1955: | | | |
| September | 217,000 | 27,498 | 12.7 |
| October | 128,600 | 12,063 | 9.4 |
| November | 158,200 | 0 | 0 |
| TOTAL | 503,800 | 39,561 | 7.9 |
| 1956: | | | |
| August | 608,600 | 25,742 | 4.2 |
| September | 2,625,700 | 172,274 | 6.6 |
| October | 253,200 | 0 | 0 |
| November | 157,000 | 0 | 0 |
| December | 8,700 | 0 | 0 |
| TOTAL | 3,653,200 | 198,016 | 5.4 |
| 1957: | | | |
| July | 99,600 | 47,088 | 47.3 |
| August | 888,300 | 244,821 | 27.6 |
| September | 991,400 | 315,263 | 31.8 |
| October | 690,000 | 425,231 | 61.6 |
| November | 32,200 | 0 | 0 |
| TOTAL | 2,701,500 | 1,032,403 | 38.2 |
| 1958: | | | |
| July | 1,093,300 | 422,126 | 38.6 |
| August | 5,682,100 | 1,902,858 | 33.5 |
| September | 2,496,700 | 1,024,362 | 41.0 |
| October | 480,800 | 247,964 | 51.6 |
| November | 1,100 | 0 | 0 |
| TOTAL | 9,754,000 | 3,597,310 | 36.9 |

Table 1 (Continued)

| Assigned Month | Total Catch (Pounds) | Pounds Sampled | Per Cent of Catch Sampled |
|---|---|---|---|
| 1959: | | | |
| July | 1,974,100 | 677,018 | 34.3 |
| August | 5,398,100 | 1,993,200 | 36.9 |
| September | 2,610,100 | 1,048,281 | 40.2 |
| October | 479,100 | 70,496 | 14.7 |
| November | 111,600 | 0 | 0 |
| December | 1,100 | 0 | 0 |
| TOTAL | 10,514,100 | 3,788,995 | 35.8 |
| 1960: | | | |
| July | 188,500 | 95,992 | 50.9 |
| August | 1,874,700 | 664,215 | 35.4 |
| September | 2,007,500 | 535,460 | 26.7 |
| October | 386,400 | 133,894 | 34.7 |
| November | 105,400 | 0 | 0 |
| TOTAL | 4,562,500 | 1,409,561 | 30.9 |

Table 2
Oregon Albacore Landings by Year, Month, and Port
1951

| Port | July | August | September | October | November | Total |
|---|---|---|---|---|---|---|
| ASTORIA | | | | | | |
| Pounds | 25,527 | 186,450 | 667,145 | 1,012,583 | 90,878 | 1,982,583 |
| No. of Landings | 17 | 72 | 53 | 63 | 15 | 220 |
| TILLAMOOK | | | | | | |
| Pounds | | 3,088 | | | 9,692 | 12,780 |
| No. of Landings | | 2 | | | 1 | 3 |
| DEPOE BAY | | | | | | |
| Pounds | 273 | | | | | 273 |
| No. of Landings | 1 | | | | | 1 |
| NEWPORT | | | | | | |
| Pounds | 9,686 | 24,665 | 633,642 | 236,100 | | 904,093 |
| No. of Landings | 7 | 15 | 74 | 16 | | 112 |
| COOS BAY | | | | | | |
| Pounds | 5,697 | 2,583 | 1,861 | 3,992 | 1,034 | 15,167 |
| No. of Landings | 1 | 4 | 3 | 2 | 1 | 11 |
| COQUILLE | | | | | | |
| Pounds | | | | 1,649 | | 1,649 |
| No. of Landings | | | | 1 | | 1 |
| TOTAL | 41,183 | 216,786 | 1,302,648 | 1,254,324 | 101,604 | 2,916,545 |
| | 26 | 93 | 130 | 82 | 17 | 348 |

Table 2 (Continued)
1952

| Port | July | August | September | October | November | December | Total |
|---|---|---|---|---|---|---|---|
| ASTORIA | | | | | | | |
| Pounds | 10,050 | 8,039 | 284,663 | 792,615 | 252,102 | 52,591 | 1,400,060 |
| No. of Landings | 7 | 5 | 25 | 85 | 41 | 6 | 169 |
| DEPOE BAY | | | | | | | |
| Pounds | | | 4,265 | | | | 4,265 |
| No. of Landings | | | 1 | | | | 1 |
| NEWPORT | | | | | | | |
| Pounds | 3,944 | 106,223 | 907,669 | 47,301 | | | 1,065,137 |
| No. of Landings | 8 | 19 | 93 | 5 | | | 125 |
| COOS BAY | | | | | | | |
| Pounds | | 8,837 | 102,568 | 123 | 4,364 | | 115,892 |
| No. of Landings | | 5 | 19 | 1 | 1 | | 26 |
| TOTAL | 13,994 | 123,099 | 1,299,165 | 840,039 | 256,466 | 52,591 | 2,585,354 |
| | 15 | 29 | 138 | 91 | 42 | 6 | 321 |

1953

| Port | August | September | October | November | Total |
|---|---|---|---|---|---|
| ASTORIA | | | | | |
| Pounds | 21,378 | 60,238 | 145,289 | | 226,905 |
| No. of Landings | 2 | 10 | 32 | | 44 |
| NEWPORT | | | | | |
| Pounds | | 505,950 | 41,365 | 1,000 | 548,315 |
| No. of Landings | | 39 | 16 | 1 | 56 |
| COOS BAY | | | | | |
| Pounds | | | 547 | | 547 |
| No. of Landings | | | 1 | | 1 |
| TOTAL | 21,378 | 566,188 | 187,201 | 1,000 | 775,767 |
| | 2 | 49 | 49 | 1 | 101 |

Table 2 (Continued)
1954

| Port | September | October | November | Total |
|---|---|---|---|---|
| ASTORIA | | | | |
| Pounds | 33,054 | 262,381 | 8,115 | 303,550 |
| No. of Landings | 4 | 39 | 4 | 47 |
| TILLAMOOK | | | | |
| Pounds | | | 2,122 | 2,122 |
| No. of Landings | | | 1 | 1 |
| NEWPORT | | | | |
| Pounds | 61,562 | 67,552 | | 129,114 |
| No. of Landings | 9 | 13 | | 1 |
| COOS BAY | | | | |
| Pounds | 4,336 | 30,318 | | 34,654 |
| No. of Landings | 5 | 4 | | 9 |
| TOTAL | 98,952 | 360,251 | 10,237 | 469,440 |
| | 18 | 56 | 5 | 79 |

1955

| Port | September | October | November | Total |
|---|---|---|---|---|
| ASTORIA | | | | |
| Pounds | 7,557 | 275,041 | 158,212 | 440,810 |
| No. of Landings | 1 | 18 | 17 | 36 |
| NEWPORT | | | | |
| Pounds | 19,324 | 37,690 | | 57,014 |
| No. of Landings | 3 | 2 | | 5 |
| COOS BAY | | | | |
| Pounds | | 5,480 | | 5,480 |
| No. of Landings | | 1 | | 1 |
| TOTAL | 26,881 | 318,211 | 158,212 | 503,304 |
| | 4 | 21 | 17 | 42 |

Table 2 (Continued)
1956

| Port | August | September | October | November | December | Total |
|---|---|---|---|---|---|---|
| ASTORIA | | | | | | |
| Pounds | 208,832 | 2,310,558 | 415,568 | 156,962 | 7,594 | 3,099,514 |
| No. of Landings | 32 | 187 | 37 | 13 | 3 | 272 |
| TILLAMOOK | | | | | | |
| Pounds | 4,008 | 98 | | | 1,133 | 5,239 |
| No. of Landings | 3 | 1 | | | 1 | 5 |
| DEPOE BAY | | | | | | |
| Pounds | 3,339 | 8,814 | | | | 12,153 |
| No. of Landings | 2 | 1 | | | | 3 |
| NEWPORT | | | | | | |
| Pounds | 217,130 | 290,117 | 9,124 | | | 516,371 |
| No. of Landings | 82 | 50 | 5 | | | 137 |
| FLORENCE | | | | | | |
| Pounds | 6,534 | 42 | | | | 6,576 |
| No. of Landings | 5 | 1 | | | | 6 |
| WINCHESTER | | | | | | |
| Pounds | 1,814 | | | | | 1,814 |
| No. of Landings | 1 | | | | | 1 |
| COOS BAY | | | | | | |
| Pounds | 5,825 | 5,608 | | | | 11,433 |
| No. of Landings | 4 | 2 | | | | 6 |
| TOTAL | 447,482 | 2,615,237 | 424,692 | 156,962 | 8,727 | 3,653,100 |
| | 129 | 242 | 42 | 13 | 4 | 430 |

1957

| Port | July | August | September | October | November | Total |
|---|---|---|---|---|---|---|
| ASTORIA | | | | | | |
| Pounds | 50,232 | 441,547 | 466,888 | 796,109 | 31,215 | 1,785,991 |
| No. of Landings | 12 | 130 | 80 | 62 | 5 | 289 |
| TILLAMOOK | | | | | | |
| Pounds | 303 | 20,308 | 6,177 | | | 27,788 |
| No. of Landings | 1 | 22 | 6 | | | 29 |
| DEPOE BAY | | | | | | |
| Pounds | | 994 | | | | 994 |
| No. of Landings | | 2 | | | | 2 |
| NEWPORT | | | | | | |
| Pounds | 32,079 | 423,365 | 131,892 | 261,341 | 978 | 849,655 |
| No. of Landings | 6 | 206 | 41 | 42 | 2 | 297 |
| FLORENCE | | | | | | |
| Pounds | | 2,159 | 872 | 2,281 | | 5,312 |
| No. of Landings | | 2 | 1 | 2 | | 5 |
| WINCHESTER | | | | | | |
| Pounds | | | | 147 | | 147 |
| No. of Landings | | | | 1 | | 1 |
| COOS BAY | | | | | | |
| Pounds | 45 | 7,598 | 20,545 | 4,340 | | 32,528 |
| No. of Landings | 3 | 1 | 4 | 3 | | 11 |
| NESTUCCA | | | | | | |
| Pounds | | 92 | | | | 92 |
| No. of Landings | | 2 | | | | 2 |
| TOTAL | 82,659 | 896,063 | 626,374 | 1,064,218 | 32,193 | 2,701,507 |
| | 22 | 365 | 132 | 110 | 7 | 636 |

Table 2 (Continued)
1958

| Port | July | August | September | October | November | Total |
|---|---|---|---|---|---|---|
| ASTORIA | | | | | | |
| Pounds | 148,051 | 2,817,481 | 1,746,260 | 798,017 | 1,066 | 5,510,875 |
| No. of Landings | 19 | 314 | 192 | 104 | 1 | 630 |
| TILLAMOOK | | | | | | |
| Pounds | | 5,108 | 5,287 | 2,657 | | 13,052 |
| No. of Landings | | 8 | 3 | 3 | | 14 |
| DEPOE BAY | | | | | | |
| Pounds | 86 | 37,118 | 3,955 | 563 | | 41,722 |
| No. of Landings | 2 | 37 | 7 | 1 | | 47 |
| NEWPORT | | | | | | |
| Pounds | 213,664 | 1,879,634 | 401,183 | 91,421 | | 2,585,902 |
| No. of Landings | 72 | 449 | 112 | 35 | | 668 |
| FLORENCE | | | | | | |
| Pounds | | 21,001 | | 713 | | 21,714 |
| No. of Landings | | 11 | | 1 | | 12 |
| WINCHESTER | | | | | | |
| Pounds | | | 98 | | | 98 |
| No. of Landings | | | 1 | | | 1 |
| COOS BAY | | | | | | |
| Pounds | 31,560 | 612,176 | 884,193 | 51,136 | | 1,579,065 |
| No. of Landings | 11 | 145 | 121 | 13 | | 290 |
| BROOKINGS | | | | | | |
| Pounds | | | 1,561 | | | 1,561 |
| No. of Landings | | | 2 | | | 2 |
| TOTAL | 393,361 | 5,372,518 | 3,042,537 | 944,507 | 1,066 | 9,753,989 |
| | 104 | 964 | 438 | 157 | 1 | 1,664 |

1959

| Port | July | August | September | October | November | December | Total |
|---|---|---|---|---|---|---|---|
| ASTORIA | | | | | | | |
| Pounds | 364,061 | 2,409,420 | 3,096,395 | 528,062 | 111,597 | 1,060 | 6,510,595 |
| No. of Landings | 69 | 337 | 440 | 57 | 14 | 1 | 918 |
| TILLAMOOK | | | | | | | |
| Pounds | 9,912 | 18,892 | 381 | | | | 29,185 |
| No. of Landings | 5 | 11 | 3 | | | | 19 |
| DEPOE BAY | | | | | | | |
| Pounds | 4,798 | 30,496 | 4,321 | | | | 39,615 |
| No. of Landings | 4 | 26 | 6 | | | | 36 |
| NEWPORT | | | | | | | |
| Pounds | 835,682 | 1,528,997 | 524,212 | 21,206 | | | 2,910,097 |
| No. of Landings | 190 | 329 | 87 | 6 | | | 612 |
| FLORENCE | | | | | | | |
| Pounds | 2,817 | 1,407 | 1,112 | | | | 5,336 |
| No. of Landings | 2 | 1 | 1 | | | | 4 |
| WINCHESTER | | | | | | | |
| Pounds | 188 | 1,441 | | | | | 1,629 |
| No. of Landings | 1 | 1 | | | | | 2 |
| COOS BAY | | | | | | | |
| Pounds | 226,639 | 90,724 | 733,267 | 24,310 | | | 1,074,940 |
| No. of Landings | 49 | 14 | 68 | 4 | | | 135 |
| PACIFIC OCEAN | | | | | | | |
| Pounds | | | 837 | | | | 837 |
| No. of Landings | | | 2 | | | | 2 |
| BROOKINGS | | | | | | | |
| Pounds | | 220 | 1,576 | | | | 1,796 |
| No. of Landings | | 1 | 2 | | | | 3 |
| TOTAL | 1,444,097 | 4,081,597 | 4,362,101 | 573,578 | 111,597 | 1,060 | 10,574,030 |
| | 321 | 721 | 607 | 67 | 14 | 1 | 1,731 |

Table 2 (Continued)
1960

| Port | July | August | September | October | November | Total |
|---|---|---|---|---|---|---|
| ASTORIA | | | | | | |
| Pounds | 3,596 | 783,913 | 2,248,998 | 910,312 | 105,415 | 4,052,234 |
| No. of Landings | 3 | 123 | 240 | 74 | 8 | 448 |
| TILLAMOOK | | | | | | |
| Pounds | 298 | 6,981 | 447 | | | 7,726 |
| No. of Landings | 1 | 7 | 2 | | | 10 |
| DEPOE BAY | | | | | | |
| Pounds | 916 | 3,203 | 6,097 | | | 10,216 |
| No. of Landings | 2 | 1 | 6 | | | 9 |
| NEWPORT | | | | | | |
| Pounds | 14,316 | 97,805 | 201,850 | 14,645 | | 328,616 |
| No. of Landings | 6 | 23 | 69 | 2 | | 100 |
| WINCHESTER | | | | | | |
| Pounds | | | 241 | | | 241 |
| No. of Landings | | | 1 | | | 1 |
| COOS BAY | | | | | | |
| Pounds | | 8,072 | 147,605 | 6,576 | | 162,253 |
| No. of Landings | | 2 | 14 | 1 | | 17 |
| BROOKINGS | | | | | | |
| Pounds | | | | 1,309 | | 1,309 |
| No. of Landings | | | | 1 | | 1 |
| TOTAL | 19,126 | 899,974 | 2,605,238 | 932,842 | 105,415 | 4,562,595 |
| | 12 | 156 | 332 | 78 | 8 | 586 |

Table 3
Per Cent of the Total Oregon Albacore Landings
Assigned to One-Degree Blocks, 1951-60

| Year | Per Cent Assigned |
|---|---|
| 1951 | 53.9 |
| 1952 | 84.2 |
| 1953 | 96.9 |
| 1954 | 62.9 |
| 1955 | 56.2 |
| 1956 | 81.7 |
| 1957 | 95.5 |
| 1958 | 78.9 |
| 1959 | 94.7 |
| 1960 | 90.0 |

Table 4
Albacore Catches--1951

| Area of Catch | July | | | August | | | September | | | November | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Astoria<br>Jig Boats | | | | | | | |
| 45-125 | 6,013<br>(54) | 87,600<br>(782) | 112 | 586<br>(45) | 8,200<br>(631) | 13 | | | | | | |
| 46-125 | | | | 376<br>(29) | 5,600<br>(430) | 13 | | | | | | |
| 47-125 | | | | 764<br>(29) | 11,400<br>(438) | 26 | | | | | | |
| 45-124 | 1,836<br>(40) | 22,600<br>(490) | 46 | 4,000<br>(61) | 45,300<br>(686) | 66 | | | | | | |
| 46-124 | 1,744<br>(38) | 31,200<br>(677) | 46 | | | | | | | | | |
| 43-125 | | | | | | | 7,872<br>(55) | 96,900<br>(678) | 143 | | | |
| 44-125 | | | | | | | 28,024<br>(84) | 344,700<br>(1,038) | 332 | | | |
| 38-125 | | | | | | | 12,500<br>(133) | 154,000<br>(1,638) | 94 | | | |
| 39-125 | | | | | | | 10,465<br>(132) | 128,400<br>(1,625) | 79 | | | |
| 36-122 | | | | | | | | | | 2,900<br>(42) | 41,300<br>(599) | 69 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 37-123 | | | | | | | | 3,493 (42) | 49,600 (598) | 83 |
| 38-124 | | | | | 15,648 (198) | 178,700 (2,262) | 79 | | | |
| 39-124 | | | | | 15,665 (196) | 178,900 (2,236) | 80 | | | |
| TOTAL | | 141,400 | | 70,500 | | 1,081,600 | | | 90,900 | |

Landed at Newport
Jig Boats

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 45-125 | 1,568 (30) | 20,500 (394) | 52 | 7,779 (28) | 106,800 (383) | 279 | | | | |
| 40-124 | | | | 3,945 (30) | 61,900 (465) | 133 | | | | |
| TOTAL | | 20,500 | | | 168,700 | | | 585,900 | | 0 |
| GRAND TOTAL | | 161,900 | | | 239,200 | | | 1,667,500 | | 90,900 |

Table 5
Albacore Catches--1952

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 45-125 | 612 (22) | 10,000 (357) | 28 | | | | | | | | | |
| 40-125 | | | | 608 (203) | 7,600 (2,533) | 3 | 176 (59) | 2,200 (733) | 3 | 3,164 (62) | 42,300 (829) | 51 |
| 41-125 | | | | 147 (37) | 1,800 (450) | 4 | 4,120 (89) | 51,000 (1,109) | 46 | | | |
| 41-126 | | | | | | | 4,194 (58) | 53,700 (746) | 72 | | | |
| 42-125 | | | | | | | 513 (105) | 6,500 (1,300) | 5 | | | |
| 42-126 | | | | | | | 1,139 (95) | 14,300 (1,192) | 12 | | | |
| 39-125 | | | | | | | 88 (88) | 1,100 (1,100) | 1 | 3,863 (50) | 54,900 (713) | 77 |
| 36-122 | | | | | | | | | | 529 (88) | 7,300 (1,217) | 6 |
| 37-123 | | | | 88 (88) | 1,100 (1,100) | 1 | | | | 1,278 (67) | 18,500 (974) | 19 |
| 37-124 | | | | | | | | | | 801 (62) | 9,900 (762) | 13 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 38-124 | | | 88<br>(88) | 1,100<br>(1,100) | 1 | 88<br>(44) | 1,100<br>(550) | 2 | 23,015<br>(59) | 19,000<br>(818) | 390 |
| 39-124 | | | | | | 88<br>(88) | 1,100<br>(1,100) | 1 | 4,699<br>(61) | 64,000<br>(831) | 77 |
| Subtotal | 10,000 | | | 11,600 | | | 131,000 | | | 515,900 | |
| | | | | | Bait Boats | | | | | | |
| 41-125 | | | | | | 3,323<br>(256) | 43,700<br>(3,362) | 13 | | | |
| 41-126 | | | | | | 12,291<br>(384) | 147,500<br>(4,609) | 32 | | | |
| 37-124 | | | | | | | | | 368<br>(61) | 4,900<br>(817) | 6 |
| 38-124 | | | | | | | | | 16,225<br>(115) | 215,800<br>(1,530) | 141 |
| 39-124 | | | | | | | | | 1,113<br>(59) | 14,800<br>(779) | 19 |
| Subtotal | 0 | | | 0 | | | 191,200 | | | 235,500 | |
| TOTAL | 10,000 | | | 11,600 | | | 322,200 | | | 751,400 | |
| | | | | | Landed at Newport<br>Jig Boats | | | | | | |
| 40-125 | | | 3,605<br>(134) | 43,400<br>(1,607) | 27 | 2,528<br>(843) | 31,500<br>(1,050) | 30 | | | |
| 41-125 | | | 7,331<br>(133) | 89,600<br>(1,629) | 55 | 33,739<br>(105) | 432,200<br>(1,346) | 321 | | | |

Table 5 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Newport Jig Boats | | | | | | | |
| 41-126 | | | | | | | 21,249 (105) | 273,900 (1,349) | 203 | | | |
| 42-125 | | | | | | | 1,826 (114) | 22,300 (1,394) | 16 | | | |
| 42-124 | | | | 2,090 (105) | 25,200 (1,260) | 20 | | | | | | |
| 39-125 | | | | | | | 3,978 (166) | 50,200 (2,092) | 24 | | | |
| 35-122 | | | | | | | 274 (39) | 4,700 (671) | 7 | | | |
| 36-123 | | | | | | | 274 (39) | 4,700 (671) | 7 | | | |
| 37-123 | | | | | | | 957 (60) | 13,800 (863) | 16 | | | |
| 38-124 | | | | | | | 3,023 (98) | 36,700 (1,184) | 31 | | | |
| 39-124 | | | | | | | 140 (47) | 2,400 (800) | 3 | | | |
| 34-122 | | | | | | | 274 (39) | 4,700 (671) | 7 | | | |
| TOTAL | | 3,900 | | | 158,200 | | | 877,100 | | | 25,900 | |
| GRAND TOTAL | | 13,900 | | | 169,800 | | | 1,199,300 | | | 777,300 | |

Table 6
Albacore Catches--1953

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 35-124 | | | | | | | 429 (43) | 3,800 (380) | 10 | | | |
| 36-123 | | | | 2,679 (141) | 32,900 (1,732) | 19 | 893 (149) | 11,000 (1,833) | 6 | | | |
| 36-124 | | | | | | | 5,784 (51) | 56,600 (501) | 113 | | | |
| 37-124 | | | | | | | 701 (21) | 8,600 (253) | 34 | 106 (8) | 1,100 (79) | 14 |
| 38-124 | | | | | | | 993 (37) | 9,900 (367) | 27 | 1,361 (36) | 13,500 (355) | 38 |
| 31-122 | | | | 2,436 (162) | 21,400 (1,427) | 15 | | | | | | |
| Subtotal | | 0 | | | 54,300 | | | 89,900 | | | 14,600 | |
| **Bait Boats** | | | | | | | | | | | | |
| 35-124 | | | | | | | | | | 2,468 (80) | 31,100 (1,003) | 31 |
| 36-123 | | | | | | | 738 (74) | 9,300 (930) | 10 | | | |
| 36-124 | | | | | | | | | | 1,230 (72) | 15,500 (912) | 17 |

Table 6 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria Bait Boats** | | | | | | | | | | | | |
| 34-125 | | | | | | | | | | 984 (70) | 12,400 (886) | 14 |
| Subtotal | 0 | | | 0 | | | 9,300 | | | | 59,000 | |
| TOTAL | 0 | | | 54,300 | | | 99,200 | | | | 73,600 | |
| **Landed at Newport Jig Boats** | | | | | | | | | | | | |
| 40-127 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |
| 41-127 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |
| 36-125 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |
| 37-125 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |
| 37-126 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |
| 38-126 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |
| 38-127 | | | | | | | 1,033 (86) | 11,300 (942) | 12 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 39-127 | | | 1,033 (86) | 11,300 (942) | 12 |
| 35-122 | | | 3,837 (80) | 40,600 (846) | 48 |
| 35-124 | | | 1,033 (86) | 11,300 (942) | 12 |
| 36-123 | | | 23,570 (76) | 235,700 (755) | 312 |
| 37-123 | | | 2,883 (80) | 30,500 (847) | 36 |
| 38-124 | | | 3,828 (80) | 40,500 (844) | 48 |
| 33-121 | | | 1,033 (86) | 11,300 (942) | 12 |
| 33-122 | | | 1,033 (86) | 11,300 (942) | 12 |
| 33-123 | | | 1,033 (86) | 11,300 (942) | 12 |
| 34-121 | | | 2,883 (80) | 30,500 (847) | 36 |
| 34-124 | | | 1,033 (86) | 11,300 (942) | 12 |
| TOTAL | 0 | 0 | | 524,700 | 22,600 |
| GRAND TOTAL | 0 | 54,300 | | 623,900 | 96,200 |

Table 7
Albacore Catches--1954

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Astoria<br>Jig Boats | | | | | | | |
| 40-125 | | | | | | | 328<br>(41) | 3,800<br>(475) | 8 | | | |
| 39-125 | | | | | | | 328<br>(41) | 3,800<br>(475) | 8 | | | |
| 35-122 | | | | | | | 1,778<br>(66) | 14,600<br>(541) | 27 | 9,800<br>(110) | 79,000<br>(888) | 89 |
| 36-123 | | | | | | | 3,602<br>(75) | 39,500<br>(823) | 48 | 1,300<br>(62) | 14,300<br>(681) | 21 |
| 37-123 | | | | | | | 328<br>(41) | 3,800<br>(475) | 8 | | | |
| 37-124 | | | | | | | 246<br>(18) | 2,900<br>(207) | 14 | | | |
| 38-124 | | | | | | | 328<br>(41) | 3,800<br>(475) | 8 | | | |
| 33-125 | | | | 288<br>(17) | 3,400<br>(200) | 17 | 5,601<br>(122) | 61,000<br>(1,326) | 46 | 1,529<br>(118) | 16,700<br>(1,285) | 13 |
| 33-126 | | | | | | | 1,312<br>(62) | 14,300<br>(681) | 21 | | | |
| 34-126 | | | | 246<br>(18) | 2,900<br>(207) | 14 | 2,647<br>(78) | 28,800<br>(847) | 34 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32-119 | | 246 | 2,900 | 14 | | |
| | | (18) | (207) | | | |
| TOTAL | 0 | | 9,200 | | 176,300 | 110,000 |

Table 8
Albacore Catches--1955

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Number of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Astoria<br>Jig Boats | | | | | | | |
| 35-124 | | | | | | | 7,509<br>(78) | 81,100<br>(845) | 96 | | | |
| 36-124 | | | | | | | | | | 9,419<br>(119) | 105,300<br>(1,332) | 79 |
| 31-122 | | | | | | | 8,997<br>(79) | 96,600<br>(847) | 114 | | | |
| TOTAL | | 0 | | | 0 | | | 177,700 | | | 105,300 | |

Table 9
Albacore Catches--1956

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 45-125 | | | | | | | 11,535 (152) | 144,300 (1,899) | 76 | | | |
| 45-126 | | | | 16,267 (92) | 214,500 (1,212) | 177 | 80,432 (151) | 1,079,400 (2,033) | 531 | | | |
| 44-125 | | | | 6,540 (74) | 103,600 (1,177) | 88 | | | | | | |
| 44-126 | | | | 4,220 (299) | 66,900 (474) | 141 | 84,101 (153) | 1,080,700 (1,961) | 551 | | | |
| TOTAL | | 0 | | | 385,000 | | | 2,304,400 | | | 245,500 | |
| **Landed at Newport** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 45-125 | | | | | | | 1,247 (54) | 15,500 (674) | 23 | | | |
| 45-126 | | | | | | | 5,671 (135) | 68,900 (1,640) | 42 | | | |
| 45-127 | | | | | | | 3,375 (281) | 40,400 (3,367) | 12 | | | |
| 43-125 | | | | | | | 6,782 (234) | 84,300 (2,907) | 29 | | | |

Table 9 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Newport<br>Jig Boats | | | | | | | |
| 44-126 | | | | | | | 6,351<br>(108) | 85,100<br>(1,442) | 59 | | | |
| TOTAL | 0 | | | 217,100 | | | 294,200 | | | 5,000 | | |
| GRAND TOTAL | 0 | | | 602,100 | | | 2,598,600 | | | 250,500 | | |

Table 10
Albacore Catches--1957

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria Jig Boats** | | | | | | | | | | | | |
| 45-126 | 354 (59) | 4,300 (717) | 6 | | | | 458 (115) | 5,700 (1,425) | 4 | | | |
| 46-125 | 652 (47) | 9,000 (643) | 14 | 1,509 (44) | 24,300 (715) | 34 | | | | | | |
| 46-126 | 655 (50) | 8,800 (677) | 13 | 68 (14) | 1,100 (220) | 5 | | | | | | |
| 47-125 | | | | 10,878 (99) | 146,100 (1,328) | 110 | 15,887 (65) | 218,600 (900) | 243 | | | |
| 47-126 | 85 (43) | 1,300 (650) | 2 | 134 (45) | 2,000 (667) | 3 | | | | | | |
| 48-126 | | | | 288 (24) | 4,500 (375) | 12 | | | | | | |
| 48-128 | 925 (29) | 10,900 (341) | 32 | | | | | | | | | |
| 49-126 | | | | 80 (16) | 1,200 (240) | 5 | | | | | | |
| 45-124 | | | | 5,993 (50) | 81,200 (677) | 120 | | | | | | |
| 46-124 | | | | 5,484 (64) | 73,000 (849) | 86 | | | | | | |

Table 10 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Astoria<br>Jig Boats | | | | | | | |
| 47-124 | | | | 402<br>(80) | 5,900<br>(1,180) | 5 | | | | | | |
| 40-125 | | | | | | | 10,004<br>(200) | 123,000<br>(2,460) | 50 | 8,332<br>(77) | 109,000<br>(1,009) | 108 |
| 40-126 | | | | | | | 8,520<br>(109) | 105,800<br>(1,356) | 78 | 7,111<br>(169) | 91,900<br>(2,188) | 42 |
| 41-125 | | | | | | | 1,807<br>(181) | 23,800<br>(2,380) | 10 | 11,488<br>(174) | 148,900<br>(2,256) | 66 |
| 41-126 | | | | 160<br>(40) | 2,000<br>(500) | 4 | | | | 1,695<br>(188) | 22,200<br>(2,467) | 9 |
| 42-125 | | | | 747<br>(107) | 9,700<br>(1,386) | 7 | 2,454<br>(205) | 32,500<br>(2,708) | 12 | 6,584<br>(178) | 85,200<br>(2,303) | 37 |
| 42-126 | | | | 994<br>(99) | 12,900<br>(1,290) | 10 | 483<br>(161) | 6,200<br>(2,067) | 3 | 9,681<br>(176) | 123,900<br>(2,253) | 55 |
| 42-127 | 1,434<br>(53) | 18,100<br>(670) | 27 | | | | | | | | | |
| 43-126 | | | | | | | 160<br>(40) | 2,000<br>(500) | 4 | | | |
| 43-127 | 533<br>(53) | 6,500<br>(659) | 10 | | | | | | | | | |
| 44-126 | 389<br>(49) | 4,800<br>(600) | 8 | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45-127 | 116<br>(58) | 1,400<br>(700) | 2 | | | | | | | | | | |
| 44-124 | | | | 2,807<br>(53) | 41,600<br>(785) | 53 | | | | | | | |
| 37-125 | | | | | | | 127<br>(127) | 1,700<br>(1,700) | 1 | | | | |
| 38-125 | | | | | | | 90<br>(90) | 1,200<br>(1,200) | 1 | | | | |
| 39-125 | | | | | | | 591<br>(148) | 7,900<br>(1,975) | 4 | 310<br>(303) | 4,500<br>(1,500) | 3 | |
| 39-126 | | | | | | | 60<br>(60) | 800<br>(800) | 1 | | | | |
| 35-122 | | | | | | | 575<br>(144) | 7,700<br>(1,925) | 4 | 450<br>(90) | 6,200<br>(1,240) | 5 | |
| 35-123 | | | | 160<br>(40) | 2,000<br>(500) | 4 | 4,619<br>(154) | 59,800<br>(1,993) | 30 | 831<br>(139) | 11,900<br>(198) | 6 | |
| 36-123 | | | | | | | 311<br>(156) | 4,500<br>(2,250) | 2 | 694<br>(174) | 9,600<br>(2,400) | 4 | |
| 37-123 | | | | | | | | | | 311<br>(311) | 4,500<br>(4,500) | 1 | |
| 38-124 | | | | 160<br>(40) | 2,000<br>(500) | 4 | 86<br>(29) | 1,200<br>(400) | 3 | 307<br>(307) | 4,400<br>(4,400) | 1 | |
| 32-120 | | | | 160<br>(40) | 2,000<br>(500) | 4 | | | | | | | |
| 34-121 | | | | | | | 381<br>(127) | 5,100<br>(1,700) | 3 | | | | |

Table 10 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 34-122 | | | | | | | 314<br>(105) | 4,200<br>(1,400) | 3 | | | |
| 34-123 | | | | | | | 791<br>(198) | 10,600<br>(2,650) | 4 | | | |
| 31-119 | | | | | | | 680<br>(170) | 8,400<br>(2,100) | 4 | | | |
| 29-118 | | | | 160<br>(40) | 2,000<br>(500) | 4 | | | | | | |
| Subtotal | | 65,100 | | | 413,500 | | | 630,700 | | | 622,200 | |
| **Bait Boats** | | | | | | | | | | | | |
| 45-124 | | | | 362<br>(72) | 4,500<br>(900) | 5 | | | | | | |
| 46-124 | | | | 1,259<br>(74) | 18,700<br>(1,100) | 17 | | | | | | |
| Subtotal | | 0 | | | 23,200 | | | 0 | | | 0 | |
| TOTAL | | 65,100 | | | 436,700 | | | 630,700 | | | 622,200 | |
| **Landed at Newport** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 46-126 | 2,603<br>(289) | 32,100<br>(3,567) | 9 | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46-124 | | | | 1,841 (63) | 23,600 (814) | 29 | 256 (85) | 3,600 (1,200) | 3 | 1,280 (46) | 21,100 (754) | 28 |
| 40-125 | | | | 907 (60) | 13,500 (900) | 15 | 5,584 (92) | 76,900 (1,261) | 61 | 217 (54) | 2,600 (650) | 4 |
| 41-125 | | | | 1,508 (66) | 22,800 (991) | 23 | 11,377 (94) | 158,000 (1,306) | 121 | 186 (62) | 2,100 (700) | 3 |
| 41-126 | | | | 276 (92) | 4,300 (1,433) | 3 | | | | | | |
| 42-125 | | | | 2,646 (68) | 38,900 (997) | 39 | 10,018 (88) | 139,200 (1,221) | 114 | 916 (51) | 14,800 (822) | 18 |
| 42-126 | | | | 2,097 (150) | 31,600 (2,257) | 14 | 4,438 (57) | 63,500 (814) | 78 | | | |
| 43-125 | 643 (107) | 8,300 (1,383) | 6 | 16,044 (108) | 220,100 (1,477) | 149 | 8,115 (88) | 114,300 (1,242) | 92 | 216 (36) | 2,600 (433) | 6 |
| 43-126 | 4,325 (79) | 55,900 (1,016) | 55 | 4,121 (108) | 48,800 (1,284) | 38 | 4,354 (85) | 61,700 (1,210) | 51 | | | |
| 44-125 | 1,242 (56) | 17,300 (786) | 22 | 34,629 (926) | 484,900 (1,296) | 374 | 9,877 (84) | 143,600 (1,217) | 118 | 2,109 (54) | 29,600 (759) | 39 |
| 44-126 | 6,669 (93) | 86,000 (1,194) | 72 | 23,150 (109) | 297,000 (1,401) | 212 | 4,714 (87) | 66,800 (1,237) | 54 | 68 (23) | 1,300 (433) | 3 |
| 44-127 | 6,241 (101) | 78,400 (1,265) | 62 | 898 (50) | 14,200 (789) | 18 | | | | | | |
| 44-124 | | | | 415 (83) | 6,100 (1,220) | 5 | | | | | | |
| 38-125 | | | | | | | 635 (79) | 9,200 (1,150) | 8 | | | |
| 39-125 | | | | 393 (56) | 6,200 (886) | 7 | 4,044 (90) | 57,100 (1,269) | 45 | | | |

Table 11
Albacore Catches--1958

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria Jig Boats** | | | | | | | | | | | | |
| 45-125 | 6,629 (71) | 92,700 (997) | 93 | 49,368 (85) | 720,200 (1,233) | 584 | 39,670 (77) | 518,200 (1,004) | 516 | 15,625 (70) | 223,300 (997) | 224 |
| 45-126 | 5,608 (95) | 72,300 (1,225) | 59 | 19,748 (119) | 250,800 (1,511) | 166 | 3,829 (85) | 53,800 (1,196) | 45 | | | |
| 45-127 | 222 (74) | 2,900 (967) | 3 | 183 (46) | 3,600 (900) | 4 | | | | | | |
| 46-125 | | | | 8,833 (77) | 122,600 (1,075) | 114 | 3,199 (89) | 38,100 (1,058) | 36 | 599 (33) | 9,800 (544) | 18 |
| 46-126 | 223 (74) | 2,900 (967) | 3 | 1,618 (162) | 20,700 (2,070) | 10 | 1,360 (76) | 17,400 (967) | 18 | | | |
| 46-127 | 114 (57) | 1,500 (750) | 2 | | | | | | | | | |
| 47-125 | | | | 4,954 (84) | 69,900 (1,185) | 59 | | | | 156 (39) | 2,500 (625) | 4 |
| 47-126 | | | | 2,120 (133) | 27,900 (1,744) | 16 | | | | | | |
| 48-125 | | | | | | | | | | 412 (52) | 6,600 (825) | 8 |
| 45-124 | 94 (47) | 1,300 (650) | 2 | 5,376 (88) | 77,300 (1,267) | 61 | | | | 1,331 (55) | 20,300 (846) | 24 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 45-124 | | 14,039 (54) | 206,800 (792) | 261 | | | | | | |
| 46-124 | | 165 (24) | 1,900 (271) | 7 | | | | | | |
| 40-125 | | | | | 5,101 (204) | 72,800 (2,912) | 25 | | | |
| 41-125 | | | | | 11,570 (161) | 161,300 (2,240) | 72 | 1,926 (193) | 25,600 (2,560) | 10 |
| 42-125 | | | | | 433 (87) | 11,700 (2,340) | 5 | 1,847 (185) | 25,100 (2,510) | 10 |
| 43-125 | | | | | 433 (87) | 11,700 (2,340) | 5 | | | |
| 44-125 | | | | | 214 (72) | 5,800 (1,933) | 3 | | | |
| 44-124 | | 16,703 (59) | 221,100 (787) | 281 | 575 (32) | 8,500 (472) | 18 | | | |
| 35-125 | | | | | 433 (87) | 11,700 (2,340) | 5 | | | |
| 35-123 | | | | | 433 (87) | 11,700 (2,340) | 5 | | | |
| 36-123 | | | | | 433 (87) | 11,700 (2,340) | 5 | | | |
| 37-124 | | | | | 433 (87) | 11,700 (2,340) | 5 | | | |
| 38-124 | | | | | 433 (87) | 11,700 (2,340) | 5 | | | |
| 39-122 | | | | | 215 (72) | 5,800 (1,933) | 3 | | | |
| TOTAL | 32,100 | | 429,800 | | | 336,100 | | | 50,700 | |
| GRAND TOTAL | 97,200 | | 866,500 | | | 966,800 | | | 672,900 | |

Table 11 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Astoria<br>Jig Boats | | | | | | | |
| 35-122 | 389<br>(56) | 4,000<br>(571) | 7 | 1,243<br>(78) | 19,400<br>(1,213) | 16 | | | | | | |
| 35-123 | | | | 98<br>(49) | 1,700<br>(850) | 2 | | | | | | |
| 36-122 | | | | 206<br>(41) | 2,900<br>(580) | 5 | | | | | | |
| 36-123 | 291<br>(58) | 4,100<br>(820) | 5 | 685<br>(62) | 10,000<br>(909) | 11 | | | | | | |
| 36-124 | | | | 98<br>(49) | 1,700<br>(850) | 2 | | | | | | |
| 37-123 | 203<br>(68) | 2,800<br>(933) | 3 | 456<br>(57) | 6,800<br>(850) | 8 | | | | | | |
| 38-124 | 202<br>(67) | 2,800<br>(933) | 3 | 556<br>(56) | 8,600<br>(860) | 10 | | | | | | |
| 39-124 | | | | 746<br>(68) | 10,900<br>(991) | 11 | 255<br>(85) | 3,600<br>(1,200) | 3 | | | |
| 32-122 | 127<br>(64) | 1,800<br>(900) | 2 | | | | | | | | | |
| 33-120 | 160<br>(40) | 2,300<br>(575) | 4 | 134<br>(45) | 1,900<br>(633) | 3 | | | | | | |
| 33-121 | | | | 329<br>(47) | 5,000<br>(714) | 7 | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33-122 | | | | 240<br>(80) | 3,700<br>(1,233) | 3 | | | | | | |
| 34-121 | 599<br>(86) | 8,400<br>(1,200) | 7 | 187<br>(62) | 2,800<br>(933) | 3 | | | | | | |
| 34-122 | 2,245<br>(112 | 31,800<br>(1,590) | 20 | 426<br>(71) | 6,300<br>(1,050) | 6 | | | | | | |
| 33-118 | 207<br>(41) | 2,900<br>(580) | 5 | | | | | | | | | |
| 33-119 | 206<br>(41) | 2,900<br>(580) | 5 | | | | | | | | | |
| Subtotal | | 483,300 | | | 2,586,700 | | | 1,525,000 | | | 336,600 | |
| | | | | Bait Boats | | | | | | | | |
| 45-125 | | | | 15,875<br>(160) | 229,400<br>(2,318) | 99 | 10,212<br>(128) | 150,100<br>(1,876) | 80 | 981<br>(65) | 12,300<br>(820) | 15 |
| 46-124 | | | | 31<br>(16) | 500<br>(250) | 2 | 787<br>(72) | 11,300<br>(1,027) | 11 | | | |
| 42-126 | | | | 1,021<br>(93) | 17,600<br>(1,600) | 11 | 2,393<br>(104) | 41,200<br>(1,791) | 23 | | | |
| 34-122 | 8,535<br>(225) | 115,900<br>(3,050) | 38 | | | | | | | | | |
| Subtotal | | 115,900 | | | 247,500 | | | 202,600 | | | 12,300 | |
| TOTAL | | 599,200 | | | 2,834,200 | | | 1,727,600 | | | 348,900 | |
| | | | | Landed at Newport<br>Jig Boats | | | | | | | | |
| 45-125 | 3,957<br>(43) | 60,500<br>(665) | 91 | 23,007<br>(61) | 385,600<br>(1,017) | 379 | | | | | | |

Table 11 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Newport<br>Jig Boats | | | | | | | |
| 45-124 | 2,309<br>(80) | 36,700<br>(1,266) | 29 | 7,043<br>(40) | 131,000<br>(749) | 175 | | | | | | |
| 43-125 | 5,635<br>(62) | 89,900<br>(988) | 91 | 4,270<br>(87) | 76,100<br>(1,553) | 49 | | | | | | |
| 43-126 | | | | 2,276<br>(1,198) | 28,400<br>(1,495) | 19 | | | | | | |
| 44-125 | | | | 35,142<br>(106) | 459,300<br>(1,388) | 331 | | | | | | |
| 44-126 | 9,122<br>(100) | 121,400<br>(1,334) | 91 | 52,536<br>(126) | 665,100<br>(1,591) | 418 | | | | | | |
| 44-124 | | | | 7,343<br>(83) | 137,100<br>(1,558) | 88 | | | | | | |
| TOTAL | | 308,500 | | | 1,882,600 | | | 344,700 | | | 50,000 | |
| GRAND TOTAL | | 907,700 | | | 4,716,800 | | | 2,072,300 | | | 398,900 | |

Table 12
Albacore Catches--1959

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| | | | | | Landed at Astoria<br>Jig Boats | | | | | | | |
| 45-125 | 19,061<br>(93) | 239,500<br>(1,174) | 204 | 65,782<br>(112) | 856,300<br>(1,459) | 587 | 32,982<br>(113) | 439,000<br>(1,498) | 293 | 1,023<br>(171) | 12,900<br>(2,150) | 6 |
| 45-126 | 3,033<br>(108) | 38,600<br>(1,379) | 28 | 4,029<br>(68) | 52,600<br>(892) | 59 | | | | | | |
| 46-125 | 4,643<br>(106) | 65,800<br>(1,495) | 44 | 91,171<br>(104) | 1,189,500<br>(1,359) | 875 | 49,659<br>(119) | 641,500<br>(1,542) | 416 | | | |
| 46-126 | 676<br>(113) | 8,500<br>(1,417) | 6 | 7,777<br>(110) | 98,600<br>(1,389) | 71 | 5,065<br>(108) | 65,800<br>(1,400) | 47 | | | |
| 47-125 | 145<br>(73) | 2,000<br>(1,000) | 2 | 31,421<br>(104) | 413,100<br>(1,372) | 301 | | | | | | |
| 47-126 | | | | 2,967<br>(90) | 37,900<br>(1,148) | 33 | | | | | | |
| 48-125 | 468<br>(117) | 6,100<br>(1,525) | 4 | 118<br>(59) | 1,400<br>(700) | 2 | | | | | | |
| 45-124 | | | | 475<br>(48) | 7,400<br>(740) | 10 | 408<br>(102) | 5,300<br>(1,325) | 4 | | | |
| 46-124 | 252<br>(126) | 3,100<br>(1,550) | 2 | 422<br>(42) | 6,200<br>(620) | 10 | 421<br>(105) | 7,900<br>(1,975) | 4 | | | |
| 40-125 | | | | 4,301<br>(119) | 54,900<br>(1,525) | 36 | 12,501<br>(162) | 183,900<br>(2,388) | 77 | 14,501<br>(175) | 191,700<br>(2,310) | 83 |

Table 12 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria Jig Boats** | | | | | | | | | | | | |
| 40-126 | | | | 762 (127) | 9,200 (153) | 6 | 7,145 (193) | 94,200 (2,546) | 37 | | | |
| 41-125 | | | | 6,200 (122) | 106,000 (2,078) | 51 | 2,287 (82) | 29,600 (1,057) | 28 | | | |
| 41-126 | | | | 4,223 (162) | 53,700 (2,065) | 26 | 334 (167) | 4,300 (2,150) | 2 | | | |
| 41-127 | | | | 938 (117) | 11,900 (1,488) | 8 | | | | | | |
| 42-125 | | | | 11,224 (163) | 143,300 (2,077) | 69 | 2,651 (166) | 36,100 (2,256) | 16 | | | |
| 42-126 | | | | 2,060 (172) | 25,900 (2,158) | 12 | 254 (127) | 3,100 (1,550) | 2 | | | |
| 43-125 | | | | 2,595 (124) | 33,500 (1,595) | 21 | 1,655 (150) | 21,600 (1,964) | 11 | | | |
| 44-125 | 3,774 (94) | 47,500 (1,188) | 40 | 10,619 (128) | 142,400 (1,716) | 83 | 2,019 (67) | 26,200 (873) | 30 | | | |
| 44-126 | 6,109 (109) | 76,300 (1,363) | 56 | 956 (96) | 12,200 (1,220) | 10 | | | | | | |
| 41-124 | | | | 3,108 (155) | 32,200 (1,610) | 20 | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44-124 | 167<br>(42) | 2,500<br>(625) | 4 | | | | | | | | | |
| 36-125 | | | | 954<br>(119) | 12,300<br>(1,538) | 8 | | | | | | |
| 37-125 | | | | | | | 1,606<br>(161) | 20,100<br>(2,010) | 10 | | | |
| 38-125 | | | | 760<br>(127) | 9,200<br>(1,533) | 6 | | | | | | |
| 39-125 | 328<br>(164) | 3,900<br>(1,950) | 2 | 3,603<br>(95) | 45,500<br>(1,197) | 38 | 13,860<br>(213) | 176,900<br>(2,722) | 65 | 12,144<br>(158) | 159,500<br>(2,071) | 77 |
| 39-126 | | | | | | | 15,384<br>(195) | 205,100<br>(2,596) | 79 | | | |
| 35-122 | 665<br>(166) | 7,900<br>(1,975) | 4 | | | | | | | | | |
| 36-123 | 665<br>(166) | 7,900<br>(1,975) | 4 | 2,755<br>(138) | 34,300<br>(1,715) | 20 | 226<br>(113) | 2,600<br>(1,300) | 2 | | | |
| 37-123 | | | | | | | 226<br>(113) | 2,600<br>(1,300) | 2 | | | |
| 37-124 | 1,666<br>(76) | 20,800<br>(945) | 22 | 872<br>(109) | 10,600<br>(1,325) | 8 | | | | | | |
| 38-124 | 665<br>(166) | 7,900<br>(1,975) | 4 | 1,225<br>(56) | 15,700<br>(714) | 22 | 223<br>(112) | 2,600<br>(1,300) | 2 | | | |
| 39-124 | 328<br>(164) | 3,900<br>(1,950) | 2 | 621<br>(155) | 6,400<br>(1,600) | 4 | 223<br>(112) | 2,600<br>(1,300) | 2 | 6,729<br>(132) | 86,600<br>(1,698) | 51 |
| 33-121 | 328<br>(164) | 3,900<br>(1,950) | 2 | | | | | | | | | |

Table 12 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 34-121 | 665 (166) | 7,900 (1,975) | 4 | | | | | | | | | |
| TOTAL | | 554,000 | | | 3,422,200 | | | 1,971,000 | | | 450,700 | |
| **Landed at Newport** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 45-125 | 64,129 (79) | 815,700 (1,000) | 816 | 79,939 (60) | 1,044,000 (788) | 1,325 | | | | | | |
| 45-126 | 11,486 (103) | 145,300 (1,297) | 112 | | | | | | | | | |
| 45-127 | 424 (141) | 5,100 (1,700) | 3 | | | | | | | | | |
| 46-125 | 616 (68) | 7,800 (867) | 9 | 2,809 (48) | 40,200 (681) | 59 | | | | | | |
| 47-125 | | | | 1,656 (46) | 23,600 (656) | 36 | | | | | | |
| 45-124 | | | | 1,067 (46) | 13,300 (578) | 23 | | | | | | |
| 42-127 | 128 (21) | 1,700 (283) | 6 | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 43-125 | | | | 1,200 (52) | 13,800 (600) | 23 | | | |
| 43-126 | 1,492 (83) | 19,700 (1,094) | 18 | | | | | | |
| 43-127 | 128 (21) | 1,700 (283) | 6 | | | | | | |
| 44-125 | 6,998 (113) | 88,500 (1,427) | 62 | 11,480 (75) | 154,400 (1,003) | 154 | | | |
| 44-126 | 6,430 (75) | 77,800 (905) | 86 | 2,845 (124) | 38,100 (1,657) | 23 | | | |
| 44-124 | 240 (60) | 2,100 (700) | 3 | | | | | | |
| TOTAL | | 1,165,400 | | | 1,327,400 | | | 405,800 | 11,600 |

Landed at Coos Bay
Jig Boats

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 45-125 | 1,854 (66) | 23,400 (836) | 28 | 1,003 (91) | 12,900 (1,173) | 11 | | | |
| 45-126 | 4,892 (71) | 62,200 (901) | 69 | 776 (129) | 9,300 (1,550) | 6 | | | |
| 46-126 | | | | 776 (129) | 9,300 (1,550) | 6 | | | |
| 47-126 | | | | 384 (128) | 4,600 (1,533) | 3 | | | |
| 40-125 | | | | 2,497 (125) | 32,200 (1,610) | 20 | 437 (44) | 5,700 (570) | 10 |

Table 12 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Coos Bay Jig Boats** | | | | | | | | | | | | |
| 40-126 | | | | 1,544 (129) | 18,500 (1,542) | 12 | | | | | | |
| 41-125 | | | | 1,646 (118) | 21,300 (1,521) | 14 | 372 (62) | 4,800 (800) | 6 | | | |
| 41-126 | | | | 24,217 (132) | 203,200 (1,642) | 184 | 3,529 (131) | 50,400 (1,867) | 27 | | | |
| 42-125 | | | | | | | 9,153 (125) | 136,300 (1,867) | 73 | | | |
| 42-126 | | | | 2,307 (165) | 28,600 (2,043) | 14 | | | | | | |
| 43-125 | 145 (24) | 1,900 (317) | 6 | | | | 933 (72) | 12,100 (931) | 13 | | | |
| 43-126 | 1,402 (82) | 17,100 (1,006) | 17 | 776 (129) | 9,300 (1,550) | 6 | | | | | | |
| 44-125 | 2,371 (66) | 29,800 (828) | 36 | 5,043 (92) | 64,800 (1,178) | 55 | | | | | | |
| 44-126 | 6,861 (89) | 86,000 (1,117) | 77 | 776 (129) | 9,300 (1,550) | 6 | | | | | | |
| 44-127 | 1,568 (143) | 19,200 (1,745) | 11 | | | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 43-124 | | | | | 292<br>(97) | 3,700<br>(1,233) | 3 |
| 38-125 | | 269<br>(90) | 3,500<br>(1,167) | 3 | | | |
| 39-125 | | 1,069<br>(89) | 13,900<br>(1,158) | 12 | | | |
| 39-126 | | 776<br>(129) | 9,300<br>(1,550) | 6 | | | |
| 35-122 | | 625<br>(69) | 8,000<br>(899) | 9 | | | |
| 36-123 | | 625<br>(69) | 8,000<br>(899) | 9 | | | |
| 37-123 | | 70<br>(23) | 1,000<br>(333) | 3 | | | |
| 37-124 | | 562<br>(94) | 7,100<br>(1,183) | 6 | | | |
| 38-124 | | 695<br>(58) | 9,000<br>(750) | 12 | | | |
| 39-124 | | 1,136<br>(126) | 14,400<br>(1,600) | 9 | 69<br>(23) | 1,000<br>(333) | 3 |
| 33-121 | | 276<br>(92) | 3,500<br>(1,167) | 3 | | | |
| 34-121 | | 276<br>(92) | 3,500<br>(1,167) | 3 | | | |
| 34-122 | | 349<br>(58) | 4,500<br>(750) | 6 | | | |
| TOTAL | 239,600 | | 608,000 | | | 214,000 | 13,300 |
| GRAND TOTAL | 1,959,000 | | 5,357,600 | | | 2,590,800 | 475,600 |

Table 13
Albacore Catches--1960

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 45-125 | 5,226 (42) | 88,500 (720) | 123 | 24,358 (81) | 421,700 (1,410) | 299 | 7,892 (52) | 124,100 (811) | 153 | | | |
| 45-126 | | | | 1,381 (99) | 26,400 (1,886) | 14 | 1,355 (62) | 21,000 (955) | 22 | | | |
| 46-125 | 1,058 (66) | 16,800 (1,050) | 16 | 27,603 (130) | 463,900 (2,188) | 212 | 14,189 (76) | 221,300 (1,183) | 187 | | | |
| 46-126 | | | | 1,837 (87) | 32,400 (1,543) | 21 | 1,812 (45) | 25,700 (643) | 40 | | | |
| 47-125 | | | | 1,385 (77) | 20,900 (1,161) | 18 | | | | | | |
| 45-124 | | | | 17,593 (127) | 302,500 (2,176) | 139 | 4,678 (61) | 88,200 (1,146) | 77 | | | |
| 46-124 | | | | 5,268 (89) | 92,600 (1,569) | 59 | 4,148 (48) | 59,100 (679) | 87 | | | |
| 40-125 | | | | | | | 40,126 (144) | 544,500 (1,952) | 279 | 2,164 (197) | 30,000 (2,727) | 11 |
| 40-126 | | | | | | | 6,659 (121) | 87,900 (1,598) | 55 | | | |
| 44-125 | 66 (33) | 1,100 (550) | 2 | 1,341 (75) | 23,200 (1,289) | 18 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44-126 | | | | 4,062 (80) | 71,300 (1,398) | 51 | 216 (54) | 2,900 (725) | 4 | | | | |
| 40-124 | | | | | | | 1,152 (165) | 15,800 (2,257) | 7 | | | | |
| 44-124 | | | | 2,905 (100) | 46,800 (1,614) | 29 | | | | | | | |
| 35-125 | | | | | | | 1,645 (118) | 20,600 (1,471) | 14 | | | | |
| 37-125 | | | | 3,929 (135) | 52,500 (1,810) | 29 | 2,791 (254) | 38,300 (3,482) | 11 | | | | |
| 38-125 | | | | 915 (83) | 13,000 (1,182) | 11 | 8,173 (115) | 110,600 (1,558) | 71 | 13,328 (159) | 179,100 (2,132) | 84 | |
| 38-126 | | | | | | | 777 (111) | 10,100 (1,443) | 7 | | | | |
| 39-125 | | | | | | | 10,348 (98) | 143,000 (1,349) | 106 | 3,430 (84) | 45,800 (1,117) | 41 | |
| 39-126 | | | | | | | 777 (111) | 10,100 (1,443) | 7 | 1,978 (104) | 26,500 (1,395) | 19 | |
| 39-127 | | | | | | | 1,189 (149) | 16,700 (2,088) | 8 | 538 (90) | 7,500 (1,250) | 6 | |
| 35-122 | 1,093 (78) | 16,400 (1,171) | 14 | 659 (66) | 9,700 (970) | 10 | 9,047 (177) | 117,300 (2,300) | 51 | | | | |
| 35-123 | | | | | | | 1,866 (170) | 25,600 (2,327) | 11 | | | | |
| 36-122 | | | | 1,789 (81) | 23,900 (1,086) | 22 | | | | | | | |

Table 13 (Continued)

| Area of Catch | July | | | August | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished | Numbers of Fish (Nos/Day) | Pounds of Fish (Lbs/Day) | Days Fished |
| **Landed at Astoria** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 36-123 | | | | 1,943 (162) | 30,200 (2,517) | 12 | | | | 557 (111) | 7,400 (1,480) | 5 |
| 36-124 | | | | 1,730 (58) | 25,900 (863) | 30 | 481 (120) | 6,600 (1,650) | 4 | | | |
| 37-123 | | | | 2,426 (81) | 32,900 (1,097) | 30 | | | | 701 (88) | 9,300 (1,163) | 8 |
| 37-124 | | | | | | | 555 (111) | 7,400 (1,480) | 5 | 146 (49) | 1,900 (633) | 3 |
| 38-124 | | | | 346 (87) | 5,200 (1,300) | 4 | 3,775 (79) | 50,400 (1,050) | 48 | 4,113 (96) | 54,900 (1,277) | 43 |
| 39-124 | | | | | | | 1,388 (87) | 19,100 (1,194) | 16 | | | |
| TOTAL | | 122,800 | | | 1,695,000 | | | 1,766,300 | | | 362,400 | |
| **Landed at Newport** | | | | | | | | | | | | |
| **Jig Boats** | | | | | | | | | | | | |
| 45-125 | 1,565 (60) | 25,700 (988) | 26 | 1,747 (46) | 32,200 (847) | 38 | | | | | | |
| 45-126 | 422 (53) | 6,300 (788) | 8 | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 45-127 | 46<br>(46) | 800<br>(800) | 1 | | | | | | |
| 46-125 | 1,463<br>(61) | 23,500<br>(979) | 24 | | | | | | |
| 46-126 | 126<br>(42) | 1,900<br>(633) | 3 | | | | | | |
| 45-124 | | | | 2,919<br>(73) | 55,900<br>(1,397) | 40 | | | |
| 44-125 | | | | 806<br>(62) | 14,900<br>(1,146) | 13 | | | |
| TOTAL | | 58,200 | | | 103,000 | | | 159,200 | 8,000 |
| GRAND TOTAL | | 181,000 | | | 1,798,000 | | | 1,925,500 | 370,400 |

Table 14
Albacore Length Frequencies
Astoria--1939
(No Area Assignment)

| Length (cm) | August | September | October |
|---|---|---|---|
| 50 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | 1 |
| 4 | | | |
| 5 | 1 | 1 | |
| 6 | | | 1 |
| 7 | 4 | | 2 |
| 8 | 7 | 2 | 1 |
| 9 | 7 | 3 | 2 |
| 60 | 9 | 6 | 4 |
| 1 | 19 | 11 | 1 |
| 2 | 58 | 28 | 9 |
| 3 | 37 | 36 | 8 |
| 4 | 72 | 43 | 21 |
| 5 | 16 | 25 | 10 |
| 6 | 18 | 28 | 23 |
| 7 | 9 | 12 | 7 |
| 8 | 7 | 10 | 4 |
| 9 | 32 | 28 | 3 |
| 70 | 22 | 27 | 4 |
| 1 | 115 | 144 | 20 |
| 2 | 91 | 97 | 15 |
| 3 | 181 | 263 | 38 |
| 4 | 163 | 273 | 75 |
| 5 | 70 | 126 | 43 |
| 6 | 116 | 224 | 84 |
| 7 | 38 | 59 | 30 |
| 8 | 45 | 89 | 54 |
| 9 | 7 | 18 | 14 |
| 80 | 11 | 20 | 14 |
| 1 | 5 | 9 | 10 |
| 2 | 3 | 1 | 2 |
| 3 | 5 | 2 | 5 |
| 4 | | | 2 |
| 5 | | 3 | 2 |
| 6 | | | 3 |
| 7 | | | |
| 8 | | 1 | |
| 9 | | | |
| 90 | | | |
| 1 | | 1 | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| TOTAL | 1,168 | 1,590 | 512 |

Table 15
Albacore Length Frequencies
Astoria--1940
(No Area Assignment)

| Length (cm) | July | August | September | October |
|---|---|---|---|---|
| 50 | 1 | | | |
| 1 | 1 | | | |
| 2 | 4 | | | |
| 3 | 6 | 1 | 1 | 1 |
| 4 | 4 | 2 | 3 | |
| 5 | 9 | 2 | | |
| 6 | 18 | 3 | 1 | 2 |
| 7 | 47 | 6 | | 1 |
| 8 | 48 | 10 | 2 | 2 |
| 9 | 79 | 12 | 1 | 1 |
| 60 | 93 | 26 | 3 | 1 |
| 1 | 74 | 20 | 3 | 1 |
| 2 | 144 | 22 | 2 | |
| 3 | 130 | 43 | 3 | 3 |
| 4 | 153 | 42 | 6 | 1 |
| 5 | 63 | 52 | 4 | |
| 6 | 75 | 47 | 9 | 3 |
| 7 | 48 | 31 | 5 | 5 |
| 8 | 23 | 42 | 6 | 2 |
| 9 | 58 | 47 | 7 | 1 |
| 70 | 43 | 45 | 4 | 4 |
| 1 | 68 | 52 | 9 | 3 |
| 2 | 65 | 90 | 4 | 1 |
| 3 | 118 | 81 | 16 | 6 |
| 4 | 93 | 118 | 13 | 4 |
| 5 | 56 | 88 | 17 | 10 |
| 6 | 46 | 65 | 27 | 12 |
| 7 | 23 | 53 | 24 | 13 |
| 8 | 13 | 30 | 24 | 13 |
| 9 | 6 | 20 | 19 | 14 |
| 80 | 3 | 11 | 15 | 10 |
| 1 | | 12 | 9 | 6 |
| 2 | 1 | 5 | 6 | 5 |
| 3 | 3 | 6 | 4 | 4 |
| 4 | | 6 | 2 | 3 |
| 5 | 2 | 5 | 1 | 4 |
| 6 | 1 | 4 | 1 | 4 |
| 7 | 1 | 2 | | 3 |
| 8 | | 1 | 3 | |
| 9 | | | 1 | 1 |
| 90 | | | 1 | 1 |
| TOTAL | 1,620 | 1,102 | 256 | 145 |
| Samples | 10 | 10 | 3 | 1 |

Table 16
Albacore Length Frequencies
Astoria--1941
(No Area Assignment)

| Length (cm) | July | August | October |
|---|---|---|---|
| 50 | 2 | | |
| 1 | 4 | 3 | |
| 2 | 2 | 11 | |
| 3 | 6 | 19 | |
| 4 | 4 | 15 | |
| 5 | 3 | 22 | 1 |
| 6 | 10 | 18 | 1 |
| 7 | 12 | 18 | 1 |
| 8 | 9 | 21 | |
| 9 | 13 | 25 | |
| 60 | 11 | 19 | 1 |
| 1 | 9 | 19 | |
| 2 | 20 | 24 | 2 |
| 3 | 57 | 42 | 2 |
| 4 | 69 | 87 | 5 |
| 5 | 88 | 109 | 4 |
| 6 | 90 | 113 | 10 |
| 7 | 59 | 109 | 10 |
| 8 | 39 | 68 | 13 |
| 9 | 21 | 50 | 4 |
| 70 | 12 | 38 | 13 |
| 1 | 15 | 19 | 7 |
| 2 | 13 | 19 | 4 |
| 3 | 14 | 33 | 4 |
| 4 | 15 | 18 | 6 |
| 5 | 12 | 17 | 6 |
| 6 | 17 | 25 | 4 |
| 7 | 9 | 22 | 9 |
| 8 | 16 | 19 | 6 |
| 9 | 8 | 8 | 4 |
| 80 | 6 | 12 | 8 |
| 1 | 7 | 7 | 7 |
| 2 | 3 | 3 | 6 |
| 3 | 5 | 2 | 12 |
| 4 | 1 | 3 | 4 |
| 5 | 2 | 4 | |
| 6 | 2 | 2 | 3 |
| 7 | 1 | | 3 |
| 8 | | | 1 |
| 9 | | | |
| 90 | | | |
| TOTAL | 686 | 1,043 | 161 |
| Samples | 5 | 5 | 2 |

Table 17
Albacore Length Frequencies
Astoria--1942
(No Area Assignment)

| Length (cm) | July | August | September | Shipped from Newport | |
|---|---|---|---|---|---|
| | | | | July | August |
| 50 | | 2 | | 1 | |
| 1 | | 1 | | | |
| 2 | 7 | 3 | | 1 | |
| 3 | 3 | 8 | | | 2 |
| 4 | 5 | 6 | | | |
| 5 | 11 | 11 | | 3 | 1 |
| 6 | 9 | 20 | | 1 | 2 |
| 7 | 9 | 47 | | 5 | 5 |
| 8 | 25 | 69 | 2 | 12 | 8 |
| 9 | 49 | 115 | 4 | 10 | 10 |
| 60 | 34 | 189 | 13 | 20 | 21 |
| 1 | 67 | 233 | 26 | 25 | 34 |
| 2 | 81 | 370 | 44 | 41 | 39 |
| 3 | 78 | 460 | 61 | 39 | 50 |
| 4 | 59 | 467 | 106 | 18 | 46 |
| 5 | 58 | 329 | 123 | 20 | 43 |
| 6 | 29 | 233 | 108 | 3 | 26 |
| 7 | 17 | 126 | 66 | 3 | 14 |
| 8 | 8 | 44 | 37 | 3 | 8 |
| 9 | 6 | 27 | 23 | 2 | |
| 70 | 5 | 25 | 10 | 2 | 1 |
| 1 | 5 | 23 | 4 | 1 | |
| 2 | 2 | 20 | 3 | 3 | |
| 3 | 7 | 42 | 5 | 2 | |
| 4 | 6 | 42 | 8 | 1 | 2 |
| 5 | 6 | 57 | 6 | | |
| 6 | 9 | 59 | 7 | 1 | |
| 7 | 8 | 44 | 4 | 3 | 1 |
| 8 | 6 | 48 | 6 | 1 | |
| 9 | 9 | 34 | 4 | | |
| 80 | 4 | 41 | 4 | | 1 |
| 1 | 2 | 25 | 5 | 1 | |
| 2 | 7 | 17 | 2 | 2 | |
| 3 | 1 | 8 | 1 | 4 | |
| 4 | 1 | 9 | | 1 | |
| 5 | 1 | 4 | 1 | | |
| 6 | 1 | 2 | | 2 | |
| 7 | | 3 | | | |
| 8 | | 2 | | | |
| 9 | | | | | |
| 90 | | 1 | | 1 | |
| TOTAL | 635 | 3,266 | 683 | 232 | 314 |
| Samples | 2 | 9 | 3 | 1 | 1 |

Table 18
Albacore Length-Frequencies
Astoria--1947
(No Area Assignment)

| Length (cm) | July | August | September | October |
|---|---|---|---|---|
| 50 | | | | |
| 1 | 1 | | | |
| 2 | 2 | | 1 | |
| 3 | 1 | 3 | 2 | 1 |
| 4 | 1 | 2 | 4 | |
| 5 | 2 | | 1 | 4 |
| 6 | 5 | 5 | 1 | 5 |
| 7 | 10 | 4 | 1 | 4 |
| 8 | 10 | 14 | 1 | 1 |
| 9 | 23 | 18 | 4 | 5 |
| 60 | 34 | 34 | 5 | 6 |
| 1 | 48 | 55 | 8 | 8 |
| 2 | 94 | 78 | 10 | 8 |
| 3 | 109 | 188 | 36 | 11 |
| 4 | 125 | 213 | 37 | 16 |
| 5 | 111 | 209 | 39 | 19 |
| 6 | 72 | 163 | 74 | 16 |
| 7 | 53 | 110 | 60 | 17 |
| 8 | 26 | 66 | 44 | 11 |
| 9 | 12 | 37 | 25 | 8 |
| 70 | 7 | 29 | 21 | 2 |
| 1 | | 20 | 13 | 4 |
| 2 | 2 | 18 | 10 | 3 |
| 3 | 1 | 10 | 4 | |
| 4 | 3 | 15 | 1 | |
| 5 | 2 | 13 | 2 | |
| 6 | | 8 | 2 | |
| 7 | 1 | 16 | | |
| 8 | 1 | 18 | 1 | |
| 9 | 1 | 8 | 3 | |
| 80 | 1 | 7 | | |
| 1 | | 8 | | |
| 2 | | 4 | | |
| 3 | 1 | 4 | | |
| 4 | | 4 | 2 | |
| 5 | | 6 | | |
| 6 | | 2 | | |
| 7 | | 1 | | |
| 8 | | 1 | | |
| 9 | | 1 | | |
| 90 | | 1 | | |
| TOTAL | 759 | 1,393 | 412 | 149 |
| Samples | 9 | 14 | 4 | 1 |

Table 19
Albacore Length Frequencies
Newport--1947
(No Area Assignment)

| Length (cm) | July 1/ | August | September | October |
|---|---|---|---|---|
| 50 | 1 | | | |
| 1 | | | 1 | |
| 2 | 1 | | 1 | |
| 3 | | 1 | 4 | 1 |
| 4 | | 5 | 3 | |
| 5 | 3 | 4 | 3 | |
| 6 | 1 | 3 | 1 | 2 |
| 7 | 5 | 3 | 5 | 1 |
| 8 | 12 | 5 | 6 | |
| 9 | 10 | 8 | 12 | 6 |
| 60 | 20 | 4 | 17 | 3 |
| 1 | 25 | 3 | 20 | 5 |
| 2 | 41 | 16 | 17 | 16 |
| 3 | 39 | 9 | 37 | 13 |
| 4 | 18 | 15 | 61 | 11 |
| 5 | 20 | 17 | 95 | 30 |
| 6 | 3 | 22 | 74 | 27 |
| 7 | 3 | 14 | 84 | 31 |
| 8 | 3 | 9 | 56 | 35 |
| 9 | 2 | 6 | 48 | 26 |
| 70 | 2 | 4 | 20 | 10 |
| 1 | 1 | | 3 | 4 |
| 2 | 3 | | 11 | 4 |
| 3 | 2 | | 3 | 5 |
| 4 | 1 | | 9 | |
| 5 | | | 1 | |
| 6 | 1 | | 1 | 1 |
| 7 | 3 | | | |
| 8 | 1 | | 2 | |
| 9 | | | 3 | 1 |
| 80 | | | 1 | 1 |
| 1 | 1 | | | |
| 2 | 2 | | 1 | |
| 3 | 4 | | 1 | |
| 4 | 1 | | | |
| 5 | | | | |
| 6 | 2 | | | 1 |
| 7 | | | | |
| 8 | | | | |
| 9 | | | 1 | |
| 90 | 1 | | | |
| TOTAL | 232 | 148 | 602 | 234 |
| Samples | 1 | 1 | 4 | 2 |

1/ Sampled at Astoria.

Table 20
Albacore Length Frequencies
Coos Bay--1947
(No Area Assignment)

| Length (cm) | September | October |
|---|---|---|
| 50 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | 4 | |
| 5 | 2 | 1 |
| 6 | 3 | 7 |
| 7 | 4 | 4 |
| 8 | 2 | 4 |
| 9 | 7 | 6 |
| 60 | 8 | 6 |
| 1 | 13 | 18 |
| 2 | 19 | 10 |
| 3 | 22 | 17 |
| 4 | 32 | 27 |
| 5 | 55 | 38 |
| 6 | 68 | 24 |
| 7 | 54 | 46 |
| 8 | 62 | 32 |
| 9 | 41 | 23 |
| 70 | 16 | 14 |
| 1 | 8 | 7 |
| 2 | 7 | 6 |
| 3 | 5 | 3 |
| 4 | 5 | 3 |
| 5 | 3 | |
| 6 | 2 | 1 |
| 7 | 1 | |
| 8 | 1 | |
| 9 | 1 | |
| 80 | 1 | |
| 1 | 2 | 1 |
| 2 | | 1 |
| 3 | 1 | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | 1 |
| 8 | | |
| 9 | | |
| 90 | | |
| TOTAL | 449 | 300 |
| Samples | 4 | 2 |

Table 21
Albacore Length Frequencies
Astoria--1948
(No Area Assignment)

| Length (cm) | July | | August | September | |
|---|---|---|---|---|---|
| 50 | | 1/ | 2 | 6 | 2/ |
| 1 | 2 | | | 5 | |
| 2 | | | | 13 | |
| 3 | 1 | | | 11 | 1 |
| 4 | 2 | 1 | 2 | 9 | 3 |
| 5 | 8 | 1 | 6 | 12 | |
| 6 | 14 | 6 | 11 | 18 | 5 |
| 7 | 21 | 5 | 16 | 12 | 8 |
| 8 | 37 | 10 | 28 | 27 | 13 |
| 9 | 57 | 11 | 34 | 37 | 9 |
| 60 | 95 | 18 | 70 | 53 | 12 |
| 1 | 141 | 32 | 70 | 54 | 21 |
| 2 | 161 | 36 | 102 | 70 | 23 |
| 3 | 143 | 24 | 100 | 51 | 28 |
| 4 | 110 | 29 | 84 | 55 | 29 |
| 5 | 38 | 9 | 41 | 30 | 15 |
| 6 | 22 | 1 | 33 | 29 | 1 |
| 7 | 11 | 5 | 19 | 15 | 7 |
| 8 | 12 | 2 | 20 | 13 | 2 |
| 9 | 20 | 3 | 32 | 17 | 2 |
| 70 | 13 | 1 | 16 | 4 | 1 |
| 1 | 12 | 3 | 8 | 9 | 1 |
| 2 | 8 | 4 | 11 | 4 | |
| 3 | 18 | 4 | 14 | 6 | |
| 4 | 19 | 2 | 15 | 10 | |
| 5 | 7 | 6 | 12 | 8 | |
| 6 | 16 | | 19 | 7 | |
| 7 | 15 | | 11 | 5 | 1 |
| 8 | 2 | 2 | 13 | 8 | |
| 9 | 2 | | 7 | 2 | 2 |
| 80 | 4 | 1 | 5 | 1 | |
| 1 | 1 | | 5 | | |
| 2 | | | 2 | | |
| 3 | | | 2 | | |
| 4 | | | 2 | | |
| 5 | | 1 | 1 | 1 | |
| 6 | | | | 1 | |
| 7 | | | | | |
| 8 | 1 | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 1,013 | 217 | 813 | 603 | 184 |
| Samples | 11 | 3 | 8 | 5 | 1 |

1/ Shipped from Grays Harbor, Washington area.
2/ Shipped from Eureka, California.

Table 22
Albacore Length Frequencies
Astoria--July 1949

| Length (cm) | Area | | | | | Not Assigned | | Total |
|---|---|---|---|---|---|---|---|---|
| | 45-125 | 46-126 | 47-126 | 44-125 | 44-126 | | | |
| 50 | | | | | | | 1/ | |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | 1 | 1 | | 1 | 3 |
| 7 | 5 | 2 | | 1 | | 1 | 4 | 13 |
| 8 | 5 | 1 | | 2 | 4 | 4 | 1 | 17 |
| 9 | 10 | 1 | | 1 | 2 | 5 | 5 | 24 |
| 60 | 1 | 7 | 5 | 9 | 3 | 12 | 9 | 46 |
| 1 | 1 | 8 | 8 | 8 | | 7 | 11 | 43 |
| 2 | 3 | 9 | 5 | 10 | 2 | 6 | 6 | 41 |
| 3 | 6 | 4 | 8 | 8 | | 5 | 4 | 35 |
| 4 | 3 | 8 | 11 | 2 | 5 | 5 | 4 | 38 |
| 5 | 7 | 7 | 5 | 2 | 6 | 2 | 6 | 35 |
| 6 | 7 | 4 | 5 | 2 | 6 | 9 | 7 | 40 |
| 7 | 9 | 12 | 8 | 4 | 11 | 7 | 16 | 67 |
| 8 | 18 | 12 | 5 | 7 | 18 | 8 | 16 | 84 |
| 9 | 12 | 20 | 12 | 10 | 6 | 5 | 9 | 74 |
| 70 | 9 | 9 | 2 | 6 | 9 | 8 | 12 | 55 |
| 1 | 6 | 10 | 3 | 3 | 6 | 4 | 11 | 43 |
| 2 | 8 | 11 | 4 | 6 | 4 | 6 | 7 | 46 |
| 3 | 2 | 6 | 2 | 2 | 5 | 2 | 6 | 25 |
| 4 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 13 |
| 5 | 3 | | 1 | | 4 | 1 | 2 | 11 |
| 6 | 3 | | 1 | 4 | 3 | 1 | | 12 |
| 7 | 1 | | | 1 | | 2 | | 4 |
| 8 | 2 | 2 | | 1 | 3 | | 1 | 9 |
| 9 | 1 | 2 | | | 1 | 2 | | 6 |
| 80 | 3 | | | | | | 2 | 5 |
| 1 | | | 1 | 1 | | 1 | | 3 |
| 2 | 1 | | | | | | | 1 |
| 3 | | | | | | 1 | 1 | 2 |
| 4 | | | | 2 | | | 1 | 3 |
| 5 | | 1 | | | | | | 1 |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | 1 | | | | | | | 1 |
| 9 | | | | | | | | |
| 90 | | | | | | | | |
| TOTAL | 130 | 139 | 88 | 95 | 100 | 105 | 143 | |
| Samples | 2 | 2 | 1 | 1 | 1 | 1 | 2 | |

1/ Shipped from Westport, Washington (Grays Harbor).

Table 23
Albacore Length Frequencies
Astoria--August 1949

| Length (cm) | Area | | | Not Assigned | | Total |
|---|---|---|---|---|---|---|
| | 47-126 | 48-127 | 50-128 | | | |
| 50 | | | | | 1/ | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | 2 | | 1 | | 3 |
| 8 | 1 | 4 | | 2 | | 7 |
| 9 | | 15 | 2 | 9 | 2 | 28 |
| 60 | 1 | 18 | 16 | 20 | 6 | 61 |
| 1 | 3 | 31 | 12 | 29 | 19 | 94 |
| 2 | 7 | 20 | 18 | 31 | 9 | 85 |
| 3 | 8 | 21 | 15 | 24 | 11 | 79 |
| 4 | 2 | 25 | 12 | 19 | 9 | 67 |
| 5 | 8 | 22 | 6 | 23 | 11 | 70 |
| 6 | 5 | 22 | 6 | 27 | 4 | 64 |
| 7 | 10 | 28 | 1 | 40 | 5 | 84 |
| 8 | 5 | 30 | 3 | 38 | 2 | 78 |
| 9 | 7 | 27 | 2 | 48 | 2 | 86 |
| 70 | 2 | 33 | 5 | 50 | 5 | 95 |
| 1 | 3 | 24 | | 38 | 3 | 68 |
| 2 | 5 | 22 | 1 | 22 | 2 | 52 |
| 3 | 2 | 4 | | 14 | 6 | 26 |
| 4 | 1 | 8 | | 14 | 3 | 26 |
| 5 | | 13 | | 4 | 1 | 18 |
| 6 | 1 | 3 | | 4 | | 8 |
| 7 | 1 | 1 | | 1 | | 3 |
| 8 | | 4 | | 1 | | 5 |
| 9 | | 4 | | 2 | | 6 |
| 80 | | 5 | | | | 5 |
| 1 | | 2 | | 2 | | 4 |
| 2 | 1 | 1 | | 2 | | 4 |
| 3 | | 1 | | 1 | | 2 |
| 4 | | | | 2 | | 2 |
| 5 | | 1 | | 1 | | 2 |
| 6 | | 1 | | | | 1 |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 90 | | | | | | |
| TOTAL | 73 | 392 | 99 | 469 | 100 | |
| Samples | 1 | 4 | 1 | 4 | 1 | |

1/ Shipped from Newport and Coos Bay.

Table 24
Albacore Length Frequencies
Astoria--September 1949
(Shipped from Designated Points,
No Area Assignment)

| Length (cm) | Eureka | Eureka & Newport | Coos Bay | Unknown | Total |
|---|---|---|---|---|---|
| 45 | | | | 1 | 1 |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 50 | 3 | | | | 3 |
| 1 | 11 | | | 5 | 16 |
| 2 | 19 | | 10 | 7 | 36 |
| 3 | 17 | | 7 | 6 | 30 |
| 4 | 18 | | 12 | 9 | 39 |
| 5 | 5 | 1 | 2 | 2 | 10 |
| 6 | 5 | 2 | 1 | 4 | 12 |
| 7 | 10 | | 1 | 4 | 15 |
| 8 | 17 | 2 | 2 | 6 | 27 |
| 9 | 33 | 14 | 5 | 18 | 70 |
| 60 | 62 | 12 | 6 | 54 | 134 |
| 1 | 109 | 18 | 26 | 68 | 221 |
| 2 | 146 | 21 | 31 | 91 | 289 |
| 3 | 81 | 5 | 20 | 62 | 168 |
| 4 | 35 | 4 | 21 | 34 | 94 |
| 5 | 12 | 4 | 7 | 8 | 31 |
| 6 | 4 | 1 | 6 | 3 | 14 |
| 7 | 2 | | 9 | 2 | 13 |
| 8 | 3 | 4 | 8 | 1 | 16 |
| 9 | 1 | 4 | 1 | 3 | 9 |
| 70 | 2 | 5 | 6 | | 13 |
| 1 | 2 | 1 | 4 | 4 | 11 |
| 2 | 1 | | 5 | 1 | 7 |
| 3 | | 1 | 1 | | 2 |
| 4 | 1 | 1 | 3 | 1 | 6 |
| 5 | | | 1 | 2 | 3 |
| 6 | | 1 | 3 | | 4 |
| 7 | | 1 | | | 1 |
| 8 | | | | | |
| 9 | | | 1 | 1 | 2 |
| 80 | | | | | |
| 1 | 1 | | | | 1 |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | 1 | 1 |
| 5 | | | 1 | | 1 |
| 6 | | | | | |
| 7 | | | | | |
| 8 | 2 | | | | 2 |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 602 | 102 | 200 | 398 | |
| Samples | 6 | 2 | 2 | 3 | |

Table 25
Albacore Length Frequencies
Astoria--July 1950

| Length (cm) | Area | | | | | | Not Assigned | Total |
|---|---|---|---|---|---|---|---|---|
| | 45-125 | 47-125 | 48-126 | 45-124 | 44-125 | 44-124 | | |
| 50 | | | | | | | | |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | 2 | | | | 2 |
| 9 | | 1 | 1 | 3 | | | | 5 |
| 60 | 1 | | 1 | 9 | | 1 | | 12 |
| 1 | | 1 | 1 | 6 | | | | 8 |
| 2 | 1 | | 3 | 12 | | 1 | | 17 |
| 3 | 2 | 3 | 5 | 6 | 1 | | | 17 |
| 4 | 1 | 1 | 1 | 4 | | 1 | | 8 |
| 5 | 3 | 3 | | 4 | | 2 | 1 | 13 |
| 6 | 8 | 2 | 1 | 5 | | | | 16 |
| 7 | 5 | 2 | 3 | 14 | | 3 | 3 | 30 |
| 8 | 5 | 4 | 2 | 17 | 2 | 9 | 5 | 44 |
| 9 | 9 | 11 | 7 | 23 | 4 | 11 | 14 | 79 |
| 70 | 19 | 22 | 13 | 27 | 5 | 19 | 14 | 119 |
| 1 | 26 | 9 | 13 | 45 | 3 | 21 | 21 | 138 |
| 2 | 34 | 11 | 16 | 23 | 5 | 8 | 8 | 105 |
| 3 | 26 | 9 | 16 | 25 | 2 | 9 | 12 | 99 |
| 4 | 18 | 10 | 3 | 15 | 3 | 3 | 7 | 59 |
| 5 | 11 | 1 | 7 | 14 | 2 | 7 | 2 | 44 |
| 6 | 8 | 3 | 1 | 5 | 4 | 2 | 2 | 25 |
| 7 | 6 | 3 | | 2 | | 1 | 2 | 14 |
| 8 | 3 | | 1 | | | 1 | 5 | 10 |
| 9 | 5 | | | 4 | | 1 | 2 | 12 |
| 80 | 4 | 1 | 4 | | | | | 9 |
| 1 | 3 | 1 | 1 | | | | 1 | 6 |
| 2 | | | | 4 | | | 1 | 5 |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | 2 | 2 | | | | | | 4 |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 90 | | | | | | | | |
| TOTAL | 200 | 100 | 100 | 269 | 31 | 100 | 100 | |
| Samples | 2 | 1 | 1 | 3 | 1 | 1 | 1 | |

Table 26
Albacore Length Frequencies
Astoria--July 1950
(Shipped from Grays Harbor, Washington)

| Length (cm) | 5° Area 45-49-125-129 |
|---|---|
| 60 | |
| 1 | |
| 2 | 1 |
| 3 | |
| 4 | |
| 5 | 1 |
| 6 | 1 |
| 7 | 1 |
| 8 | 5 |
| 9 | 17 |
| 70 | 14 |
| 1 | 12 |
| 2 | 11 |
| 3 | 6 |
| 4 | 3 |
| 5 | 5 |
| 6 | 5 |
| 7 | 2 |
| 8 | 3 |
| 9 | 6 |
| 80 | 2 |
| 1 | 3 |
| 2 | 1 |
| 3 | |
| 4 | 1 |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 100 |
| Samples | 1 |

Table 27
Albacore Length Frequencies
Astoria--August 1950

| Length (cm) | Area | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | 45-125 | 46-125 | 45-49-125-129 | 45-124 | 41-125 | 44-125 | |
| 50 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | 1 | | | 1 |
| 5 | | | | 1 | | | 1 |
| 6 | | | | 1 | 1 | | 2 |
| 7 | 4 | | | 2 | 2 | | 8 |
| 8 | 4 | | | 2 | 2 | 3 | 11 |
| 9 | 9 | 3 | | 1 | 5 | 2 | 20 |
| 60 | 15 | 1 | | 10 | 7 | 7 | 40 |
| 1 | 17 | 3 | 2 | 15 | 16 | 13 | 66 |
| 2 | 20 | 4 | 4 | 12 | 19 | 17 | 76 |
| 3 | 6 | 2 | 5 | 7 | 11 | 11 | 42 |
| 4 | 3 | 3 | 4 | 12 | 6 | 7 | 35 |
| 5 | | 2 | 6 | 3 | 4 | 5 | 20 |
| 6 | 4 | 5 | 3 | 1 | 1 | 1 | 15 |
| 7 | | 7 | 2 | 3 | 2 | 3 | 17 |
| 8 | 2 | 10 | 5 | 1 | 3 | 1 | 22 |
| 9 | 2 | 5 | 11 | 4 | 2 | 4 | 28 |
| 70 | 5 | 9 | 9 | 6 | 4 | 6 | 39 |
| 1 | 4 | 11 | 13 | 5 | 8 | 6 | 47 |
| 2 | | 8 | 12 | 6 | 4 | 7 | 37 |
| 3 | 2 | 7 | 13 | 2 | 2 | 3 | 29 |
| 4 | 2 | 6 | 8 | 2 | 1 | 2 | 21 |
| 5 | | 8 | | 1 | | 1 | 10 |
| 6 | | 1 | 2 | 1 | | | 4 |
| 7 | | 1 | 1 | | | | 2 |
| 8 | | 2 | | 1 | | | 3 |
| 9 | | | | | | | |
| 80 | | 1 | | | | | 1 |
| 1 | | 1 | | | | 1 | 2 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | 1 | | | | | | 1 |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| 90 | | | | | | | |
| TOTAL | 100 | 100 | 100 | 100 | 100 | 100 | |
| Samples | 1 | 1 | 1 | 1 | 1 | 1 | |

Table 28
Albacore Length Frequencies
Astoria--September 1950

| Length (cm) | North of Pt. Delgada | | Total |
|---|---|---|---|
| | Shipped from Coos Bay | Shipped from Eureka | |
| 50 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | 1 | 1 |
| 4 | 1 | | 1 |
| 5 | | 1 | 1 |
| 6 | 1 | 1 | 2 |
| 7 | 1 | | 1 |
| 8 | 3 | | 3 |
| 9 | 6 | 4 | 10 |
| 60 | 18 | 3 | 21 |
| 1 | 19 | 13 | 32 |
| 2 | 22 | 6 | 28 |
| 3 | 19 | 7 | 26 |
| 4 | 18 | 4 | 22 |
| 5 | 5 | 3 | 8 |
| 6 | 5 | | 5 |
| 7 | 2 | 1 | 3 |
| 8 | 5 | 1 | 6 |
| 9 | 9 | 5 | 14 |
| 70 | 9 | 3 | 12 |
| 1 | 18 | 6 | 24 |
| 2 | 9 | 12 | 21 |
| 3 | 13 | 5 | 18 |
| 4 | 7 | 8 | 15 |
| 5 | 2 | 6 | 8 |
| 6 | 3 | | 3 |
| 7 | 4 | 2 | 6 |
| 8 | | 5 | 5 |
| 9 | 1 | 1 | 2 |
| 80 | | 2 | 2 |
| TOTAL | 200 | 100 | |
| Samples | 2 | 1 | |

Table 29
Albacore Length Frequencies
Astoria--October 1950

| Length (cm) | North of Pt. Delgada | Shipped from Eureka | Total |
|---|---|---|---|
| 50 | | | |
| 1 | | | |
| 2 | 3 | | 3 |
| 3 | 1 | | 1 |
| 4 | | | |
| 5 | 2 | | 2 |
| 6 | 2 | 1 | 3 |
| 7 | 2 | 2 | 4 |
| 8 | 3 | 3 | 6 |
| 9 | 3 | 2 | 5 |
| 60 | 8 | 3 | 11 |
| 1 | 11 | 3 | 14 |
| 2 | 19 | 11 | 30 |
| 3 | 18 | 17 | 35 |
| 4 | 14 | 13 | 27 |
| 5 | 9 | 10 | 19 |
| 6 | 2 | 3 | 5 |
| 7 | | 1 | 1 |
| 8 | 1 | 2 | 3 |
| 9 | 1 | 1 | 2 |
| 70 | | 5 | 5 |
| 1 | 1 | 4 | 5 |
| 2 | | 3 | 3 |
| 3 | | 4 | 4 |
| 4 | | 3 | 3 |
| 5 | | 4 | 4 |
| 6 | | 3 | 3 |
| 7 | | 3 | 3 |
| 8 | | 1 | 1 |
| 9 | | 3 | 3 |
| 80 | | 3 | 3 |
| 1 | | | |
| 2 | | 1 | 1 |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 90 | | | |
| TOTAL | 100 | 109 | |
| Samples | 1 | 1 | |

Table 30
Albacore Length Frequencies
Newport--July 1950

| Length (cm) | Area | | | Not Assigned | Total |
|---|---|---|---|---|---|
| | 45-125 | 45-49-125-129 | 45-124 | | |
| 50 | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | 1 | | | | 1 |
| 8 | 2 | 1 | | | 3 |
| 9 | 6 | 2 | 1 | | 9 |
| 60 | 9 | 3 | | 1 | 13 |
| 1 | 7 | 1 | 1 | | 9 |
| 2 | 8 | 3 | 4 | | 15 |
| 3 | 3 | 5 | 1 | | 9 |
| 4 | 5 | 4 | 3 | | 12 |
| 5 | 4 | 4 | 2 | 1 | 11 |
| 6 | | 3 | 1 | 1 | 5 |
| 7 | 1 | 9 | 7 | | 17 |
| 8 | 2 | 12 | 9 | 1 | 24 |
| 9 | 4 | 22 | 17 | 3 | 46 |
| 70 | 3 | 35 | 35 | 3 | 76 |
| 1 | 1 | 27 | 40 | 2 | 70 |
| 2 | 2 | 15 | 37 | 1 | 55 |
| 3 | 2 | 20 | 30 | 3 | 55 |
| 4 | 3 | 16 | 14 | | 33 |
| 5 | 2 | 5 | 8 | 1 | 16 |
| 6 | | 2 | 5 | | 7 |
| 7 | | 4 | 4 | | 8 |
| 8 | 2 | | 2 | | 4 |
| 9 | | 3 | 3 | | 6 |
| 80 | | 1 | | | 1 |
| 1 | | 1 | | | 1 |
| 2 | | 2 | 1 | | 3 |
| 3 | | | 3 | | 3 |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 67 | 200 | 228 | 17 | |
| Samples | 1 | 1 | 1 | 1 | |

Table 31
Albacore Length Frequencies
Newport--August 1950

| Length (cm) | Area 47-125 | Area 44-125 | Not Assigned | Total |
|---|---|---|---|---|
| 50 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | 1 | 1 |
| 4 | | | | |
| 5 | | | | |
| 6 | | | 1 | 1 |
| 7 | | | 3 | 3 |
| 8 | | | 1 | 1 |
| 9 | | | 9 | 9 |
| 60 | 2 | 3 | 24 | 29 |
| 1 | 2 | 1 | 31 | 34 |
| 2 | | 1 | 23 | 24 |
| 3 | 3 | 3 | 17 | 23 |
| 4 | 5 | 1 | 11 | 17 |
| 5 | 1 | 1 | 8 | 10 |
| 6 | | | 2 | 2 |
| 7 | 2 | 3 | 7 | 12 |
| 8 | | 3 | 7 | 10 |
| 9 | 7 | 9 | 9 | 25 |
| 70 | 2 | 16 | 10 | 28 |
| 1 | 6 | 15 | 11 | 32 |
| 2 | 2 | 12 | 10 | 24 |
| 3 | 4 | 7 | 8 | 19 |
| 4 | | 5 | 2 | 7 |
| 5 | 1 | 2 | 3 | 6 |
| 6 | 1 | 3 | | 4 |
| 7 | | 1 | 1 | 2 |
| 8 | | 1 | | 1 |
| 9 | | | 1 | 1 |
| 80 | | | | |
| 1 | | 1 | | 1 |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | | | | |
| TOTAL | 38 | 88 | 200 | |
| Samples | 1 | 1 | 1 | |

Table 32
Albacore Length Frequencies
Newport--September 1950

| Length (cm) | Area 41-126 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | 1 |
| 4 | 3 |
| 5 | 3 |
| 6 | 1 |
| 7 | 2 |
| 8 | 11 |
| 9 | 9 |
| 60 | 17 |
| 1 | 28 |
| 2 | 32 |
| 3 | 12 |
| 4 | 10 |
| 5 | 8 |
| 6 | 3 |
| 7 | 6 |
| 8 | 4 |
| 9 | 11 |
| 70 | 9 |
| 1 | 10 |
| 2 | 11 |
| 3 | 7 |
| 4 | |
| 5 | 1 |
| 6 | |
| 7 | 2 |
| 8 | 1 |
| 9 | |
| 80 | |
| TOTAL | 202 |
| Samples | 1 |

Table 33
Albacore Length Frequencies
Astoria--July 1951

| Length (cm) | Area 45-125 | Area 46-124 | Not Assigned 1/ | Total |
|---|---|---|---|---|
| 50 | 1 | | | 1 |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | 1 | | | 1 |
| 5 | | | 3 | 3 |
| 6 | 2 | 2 | 1 | 5 |
| 7 | 7 | 1 | 3 | 11 |
| 8 | 5 | 2 | 9 | 16 |
| 9 | 14 | 2 | 4 | 20 |
| 60 | 9 | 6 | 4 | 19 |
| 1 | 20 | 6 | 11 | 37 |
| 2 | 15 | 4 | 7 | 26 |
| 3 | 16 | 5 | 6 | 27 |
| 4 | 20 | 4 | 5 | 29 |
| 5 | 15 | 5 | 2 | 22 |
| 6 | 10 | 1 | | 11 |
| 7 | 8 | 2 | 1 | 11 |
| 8 | 3 | 2 | | 5 |
| 9 | 2 | 1 | 1 | 4 |
| 70 | 2 | 1 | 1 | 4 |
| 1 | 5 | 2 | | 7 |
| 2 | 6 | 1 | | 7 |
| 3 | | 1 | | 1 |
| 4 | | 1 | | 1 |
| 5 | | | | |
| 6 | 2 | | | 2 |
| 7 | 5 | 3 | | 8 |
| 8 | 2 | | | 2 |
| 9 | 4 | 1 | | 5 |
| 80 | 1 | 4 | | 5 |
| 1 | 3 | 2 | | 5 |
| 2 | 3 | 5 | | 8 |
| 3 | 8 | 2 | | 10 |
| 4 | 2 | 1 | | 3 |
| 5 | 1 | 3 | | 4 |
| 6 | 1 | 1 | | 2 |
| 7 | | 2 | | 2 |
| 8 | | | | |
| 9 | | 1 | | 1 |
| 90 | | | | |
| TOTAL | 193 | 74 | 50 | |
| Samples | 3 | 1 | 1 | |

1/ Shipped from Bay Center, Washington.

Table 34
Albacore Length Frequencies
Astoria--August 1951

| Length (cm) | 5° Area 45-49-125-129 | Not Assigned | Total |
|---|---|---|---|
| 50 | | | |
| 1 | | | |
| 2 | | 2 | 2 |
| 3 | | 2 | 2 |
| 4 | 3 | | 3 |
| 5 | | 1 | 1 |
| 6 | 3 | 6 | 9 |
| 7 | 5 | 16 | 21 |
| 8 | 2 | 17 | 19 |
| 9 | 7 | 27 | 34 |
| 60 | 9 | 20 | 29 |
| 1 | 7 | 37 | 44 |
| 2 | 10 | 35 | 45 |
| 3 | 5 | 16 | 21 |
| 4 | 9 | 18 | 27 |
| 5 | 3 | 19 | 22 |
| 6 | 1 | 8 | 9 |
| 7 | 5 | 9 | 14 |
| 8 | | 7 | 7 |
| 9 | 2 | 3 | 5 |
| 70 | 1 | 7 | 8 |
| 1 | 3 | 8 | 11 |
| 2 | 3 | 7 | 10 |
| 3 | 3 | 6 | 9 |
| 4 | 4 | 3 | 7 |
| 5 | 1 | 4 | 5 |
| 6 | | 1 | 1 |
| 7 | 1 | 3 | 4 |
| 8 | | 4 | 4 |
| 9 | | 3 | 3 |
| 80 | 1 | 3 | 4 |
| 1 | 1 | 3 | 4 |
| 2 | 3 | | 3 |
| 3 | 1 | 1 | 2 |
| 4 | 2 | 2 | 4 |
| 5 | 2 | 1 | 3 |
| 6 | 3 | | 3 |
| 7 | | | |
| 8 | | | |
| 9 | | 1 | 1 |
| 90 | | | |
| TOTAL | 100 | 300 | |
| Samples | 1 | 3 | |

Table 35
Albacore Length Frequencies
Astoria--September 1951

| Length (cm) | Area | | | Not Assigned | | Total |
|---|---|---|---|---|---|---|
| | 43-125 | 39-125 | 35-39-120-124 | | | |
| 50 | | | | | 1/ | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | 2 | 1 | 3 |
| 4 | | | 1 | 1 | | 2 |
| 5 | | 2 | | | 3 | 5 |
| 6 | | | | 2 | 2 | 4 |
| 7 | 1 | 1 | 1 | 7 | 3 | 13 |
| 8 | | | | 7 | 8 | 15 |
| 9 | 3 | 2 | 2 | 14 | 13 | 34 |
| 60 | 2 | 7 | | 19 | 8 | 36 |
| 1 | 3 | 9 | 3 | 10 | 10 | 35 |
| 2 | 5 | 7 | 10 | 14 | 9 | 45 |
| 3 | 17 | 8 | 14 | 12 | 14 | 65 |
| 4 | 7 | 11 | 18 | 18 | 15 | 69 |
| 5 | 11 | 4 | 16 | 15 | 4 | 50 |
| 6 | 5 | 3 | 11 | 4 | 3 | 26 |
| 7 | 4 | 8 | 4 | 10 | 2 | 28 |
| 8 | 3 | 3 | 5 | 3 | 1 | 15 |
| 9 | 2 | 2 | | 2 | | 6 |
| 70 | 2 | 4 | 4 | 6 | | 16 |
| 1 | 1 | 10 | 2 | 4 | 1 | 18 |
| 2 | 2 | 5 | 3 | 1 | | 11 |
| 3 | 6 | 4 | 2 | 5 | 1 | 18 |
| 4 | 2 | 2 | | 1 | 1 | 6 |
| 5 | 3 | 2 | | 7 | | 12 |
| 6 | 3 | 1 | 1 | 4 | 1 | 10 |
| 7 | 3 | 1 | 1 | 1 | | 6 |
| 8 | 1 | | | 1 | | 2 |
| 9 | | | | | | |
| 80 | 4 | 1 | | | | 5 |
| 1 | | | | | | |
| 2 | 4 | 1 | | | | 5 |
| 3 | 1 | 1 | | | | 2 |
| 4 | 2 | | 2 | 1 | | 5 |
| 5 | 2 | 1 | | 1 | | 4 |
| 6 | 1 | | | 1 | | 2 |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 90 | | | | | | |
| TOTAL | 100 | 100 | 100 | 173 | 100 | |
| Samples | 1 | 1 | 1 | 2 | 1 | |

1/ Shipped from Bay Center, Washington.

Table 36
Albacore Length Frequencies
Astoria--October 1951

| Length (cm) | 5° Area 40-44-125-129 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | 1 |
| 7 | |
| 8 | 1 |
| 9 | 2 |
| 60 | 2 |
| 1 | 8 |
| 2 | 13 |
| 3 | 19 |
| 4 | 19 |
| 5 | 14 |
| 6 | 4 |
| 7 | 3 |
| 8 | 3 |
| 9 | 2 |
| 70 | 3 |
| 1 | 2 |
| 2 | |
| 3 | 1 |
| 4 | |
| 5 | |
| 6 | 2 |
| 7 | |
| 8 | |
| 9 | |
| 80 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | 1 |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 100 |
| Samples | 1 |

Table 37
Albacore Length Frequencies
Newport--August 1951

| Length (cm) | Area 45-125 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | 1 |
| 5 | 2 |
| 6 | 1 |
| 7 | 1 |
| 8 | 6 |
| 9 | 4 |
| 60 | 6 |
| 1 | 11 |
| 2 | 8 |
| 3 | 10 |
| 4 | 11 |
| 5 | 8 |
| 6 | 3 |
| 7 | 2 |
| 8 | 4 |
| 9 | 2 |
| 70 | 3 |
| 1 | 4 |
| 2 | |
| 3 | 4 |
| 4 | 2 |
| 5 | |
| 6 | |
| 7 | |
| 8 | 2 |
| 9 | 1 |
| 80 | |
| 1 | |
| 2 | 1 |
| 3 | 1 |
| 4 | 1 |
| 5 | |
| 6 | |
| 7 | 1 |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 100 |
| Samples | 1 |

Table 38
Albacore Length Frequencies
Astoria--July 1952

| Length (cm) | Area 45-125 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | 1 |
| 7 | 1 |
| 8 | 1 |
| 9 | |
| 60 | 2 |
| 1 | 8 |
| 2 | 5 |
| 3 | 18 |
| 4 | 17 |
| 5 | 22 |
| 6 | 13 |
| 7 | 19 |
| 8 | 19 |
| 9 | 17 |
| 70 | 24 |
| 1 | 22 |
| 2 | 32 |
| 3 | 20 |
| 4 | 20 |
| 5 | 16 |
| 6 | 10 |
| 7 | 7 |
| 8 | 6 |
| 9 | 5 |
| 80 | 2 |
| 1 | 1 |
| 2 | 1 |
| 3 | 3 |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| 1 | 1 |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| TOTAL | 313 |
| Samples | 2 |

Table 39
Albacore Length Frequencies
Astoria--August 1952

| Length (cm) | Area 41-125 | Shipped from Designated Points | | Total |
|---|---|---|---|---|
| | | Newport Oreg. | Eureka Calif. | |
| 50 | | | | |
| 1 | | | | |
| 2 | | 1 | | 1 |
| 3 | | 1 | | 1 |
| 4 | | 2 | | 2 |
| 5 | | | 1 | 1 |
| 6 | | 3 | 4 | 7 |
| 7 | | | 3 | 3 |
| 8 | 1 | 7 | 3 | 11 |
| 9 | 1 | 6 | 9 | 16 |
| 60 | 1 | 15 | 16 | 32 |
| 1 | | 29 | 29 | 58 |
| 2 | 2 | 29 | 46 | 77 |
| 3 | 2 | 53 | 36 | 91 |
| 4 | | 39 | 41 | 80 |
| 5 | 4 | 37 | 45 | 86 |
| 6 | | 28 | 34 | 62 |
| 7 | 3 | 26 | 32 | 61 |
| 8 | 1 | 15 | 13 | 29 |
| 9 | 1 | 17 | 15 | 33 |
| 70 | 3 | 12 | 12 | 27 |
| 1 | 4 | 14 | 14 | 32 |
| 2 | | 12 | 11 | 23 |
| 3 | | 6 | 9 | 15 |
| 4 | | 8 | 2 | 10 |
| 5 | | 4 | 7 | 11 |
| 6 | | 1 | 3 | 4 |
| 7 | | 4 | 2 | 6 |
| 8 | | 1 | 1 | 2 |
| 9 | | 1 | 1 | 2 |
| 80 | | | 3 | 3 |
| 1 | | | | |
| 2 | | 1 | | 1 |
| 3 | | | | |
| 4 | | 2 | | 2 |
| 5 | | 1 | | 1 |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | | | | |
| TOTAL | 23 | 375 | 392 | |
| Samples | 1 | 3 | 2 | |

Table 40
Albacore Length Frequencies
Astoria--September 1952

| Length (cm) | Area | | | Not Assigned | Total |
|---|---|---|---|---|---|
| | 41-125 | 41-126 | 40-44-125-129 | | |
| 50 | | | | | |
| 1 | 1 | | | | 1 |
| 2 | 4 | 3 | 1 | | 8 |
| 3 | 5 | 7 | 2 | | 14 |
| 4 | 5 | 3 | 3 | | 11 |
| 5 | 2 | 4 | | 1 | 7 |
| 6 | 4 | 5 | 1 | 1 | 11 |
| 7 | 6 | 7 | 3 | 2 | 18 |
| 8 | 6 | 11 | 1 | 2 | 20 |
| 9 | 11 | 11 | 4 | 5 | 31 |
| 60 | 15 | 23 | 2 | 7 | 47 |
| 1 | 30 | 38 | 5 | 10 | 83 |
| 2 | 39 | 59 | 8 | 11 | 117 |
| 3 | 29 | 65 | 13 | 9 | 116 |
| 4 | 40 | 62 | 9 | 12 | 123 |
| 5 | 24 | 53 | 12 | 5 | 94 |
| 6 | 22 | 44 | 10 | 11 | 87 |
| 7 | 8 | 25 | 3 | 7 | 43 |
| 8 | 15 | 10 | 4 | 1 | 30 |
| 9 | 11 | 7 | 3 | 3 | 24 |
| 70 | 7 | 7 | 3 | 1 | 18 |
| 1 | 8 | 14 | 2 | 4 | 28 |
| 2 | 12 | 11 | 2 | 1 | 26 |
| 3 | 9 | 3 | 2 | 2 | 16 |
| 4 | 4 | 7 | 2 | 1 | 14 |
| 5 | 4 | 4 | 1 | | 9 |
| 6 | 1 | 2 | 1 | 1 | 5 |
| 7 | 1 | 4 | | 2 | 7 |
| 8 | | 2 | 1 | | 3 |
| 9 | 1 | 4 | | | 5 |
| 80 | 1 | | | | 1 |
| 1 | | | | | |
| 2 | | 1 | | 1 | 2 |
| 3 | | | | | |
| 4 | | 1 | | | 1 |
| 5 | | 1 | | | 1 |
| 6 | | | 1 | | 1 |
| 7 | | 1 | | | 1 |
| 8 | | 1 | | | 1 |
| 9 | | | 1 | | 1 |
| 90 | | | | | |
| TOTAL | 325 | 500 | 100 | 100 | |
| Samples | 2 | 5 | 1 | 1 | |

Table 41
Albacore Length Frequencies
Astoria--September 1952

| Length (cm) | Shipped from Designated Points | | | Total |
|---|---|---|---|---|
| | Newport Oreg. | Eureka Calif. | Ft. Bragg Calif. | |
| 50 | | | | |
| 1 | | 2 | | 2 |
| 2 | 1 | 5 | | 6 |
| 3 | 3 | 8 | 1 | 12 |
| 4 | 3 | 7 | 1 | 11 |
| 5 | 1 | 5 | 2 | 8 |
| 6 | 1 | 8 | 1 | 10 |
| 7 | 4 | 7 | 3 | 14 |
| 8 | 6 | 18 | | 24 |
| 9 | 6 | 29 | 3 | 38 |
| 60 | 12 | 28 | 6 | 46 |
| 1 | 14 | 64 | 6 | 84 |
| 2 | 19 | 60 | 9 | 88 |
| 3 | 28 | 72 | 12 | 112 |
| 4 | 29 | 55 | 8 | 92 |
| 5 | 34 | 55 | 12 | 101 |
| 6 | 21 | 34 | 7 | 62 |
| 7 | 11 | 32 | 4 | 47 |
| 8 | 11 | 24 | 4 | 39 |
| 9 | 5 | 18 | 1 | 24 |
| 70 | 7 | 19 | 2 | 28 |
| 1 | 6 | 18 | 1 | 25 |
| 2 | 6 | 18 | 4 | 28 |
| 3 | 6 | 24 | 1 | 31 |
| 4 | 3 | 12 | 3 | 18 |
| 5 | 4 | 12 | 1 | 17 |
| 6 | 1 | 9 | 4 | 14 |
| 7 | 4 | 4 | 1 | 9 |
| 8 | 2 | 4 | 2 | 8 |
| 9 | | 5 | | 5 |
| 80 | | 5 | | 5 |
| 1 | | 2 | | 2 |
| 2 | 1 | 1 | | 2 |
| 3 | | | | |
| 4 | | | 1 | 1 |
| 5 | | 1 | | 1 |
| 6 | 1 | | | 1 |
| 7 | | 3 | | 3 |
| 8 | | 1 | | 1 |
| 9 | | 1 | | 1 |
| 90 | | 1 | | 1 |
| 1 | | 1 | | 1 |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| TOTAL | 250 | 672 | 100 | |
| Samples | 2 | 5 | 1 | |

Table 42
Albacore Length Frequencies
Astoria--October 1952

| Length (cm) | Area 39-125 | Area 38-124 | Total |
|---|---|---|---|
| 55 | 2 | | 2 |
| 6 | 3 | | 3 |
| 7 | 4 | | 4 |
| 8 | 2 | 1 | 3 |
| 9 | 3 | 1 | 4 |
| 60 | 1 | 6 | 7 |
| 1 | 7 | 8 | 15 |
| 2 | 6 | 9 | 15 |
| 3 | 14 | 19 | 33 |
| 4 | 4 | 21 | 25 |
| 5 | 7 | 24 | 31 |
| 6 | 12 | 24 | 36 |
| 7 | 5 | 20 | 25 |
| 8 | 8 | 15 | 23 |
| 9 | 2 | 14 | 16 |
| 70 | 2 | 10 | 12 |
| 1 | | 13 | 13 |
| 2 | 3 | 7 | 10 |
| 3 | 3 | 11 | 14 |
| 4 | 3 | 4 | 7 |
| 5 | 2 | 6 | 8 |
| 6 | 2 | 13 | 15 |
| 7 | 2 | 7 | 9 |
| 8 | | 5 | 5 |
| 9 | 1 | 2 | 3 |
| 80 | 1 | 8 | 9 |
| 1 | | 4 | 4 |
| 2 | | 5 | 5 |
| 3 | | 1 | 1 |
| 4 | | | |
| 5 | | 1 | 1 |
| 6 | | | |
| 7 | 1 | | 1 |
| 8 | | | |
| 9 | | 1 | 1 |
| 90 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | 1 | 1 |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 100 | | 1 | 1 |
| TOTAL | 100 | 262 | |
| Samples | 1 | 3 | |

Table 43
Albacore Length Frequencies
Astoria--August 1953

| Length (cm) | Area 36-123 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | 3 |
| 4 | 4 |
| 5 | 2 |
| 6 | 3 |
| 7 | 5 |
| 8 | |
| 9 | |
| 60 | 2 |
| 1 | 2 |
| 2 | 3 |
| 3 | 3 |
| 4 | 18 |
| 5 | 22 |
| 6 | 10 |
| 7 | 9 |
| 8 | 2 |
| 9 | 2 |
| 70 | |
| 1 | 1 |
| 2 | |
| 3 | |
| 4 | 1 |
| 5 | |
| 6 | 2 |
| 7 | 2 |
| 8 | 1 |
| 9 | |
| 80 | 1 |
| 1 | |
| 2 | |
| 3 | 2 |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 100 |
| Samples | 1 |

Table 44
Albacore Length Frequencies
Astoria--September 1953

| Length (cm) | Area | | Not Assigned 1/ | Total |
|---|---|---|---|---|
| | 35-124 | 35-39-120-124 | | |
| 50 | 1 | | | 1 |
| 1 | 2 | | | 2 |
| 2 | 13 | 1 | | 14 |
| 3 | 20 | | | 20 |
| 4 | 32 | | 1 | 33 |
| 5 | 39 | 6 | 3 | 48 |
| 6 | 22 | 4 | 3 | 29 |
| 7 | 17 | 4 | 4 | 25 |
| 8 | 12 | 1 | 3 | 16 |
| 9 | 2 | 2 | 1 | 5 |
| 60 | 2 | 3 | 1 | 6 |
| 1 | 2 | 2 | 4 | 8 |
| 2 | | 5 | 3 | 8 |
| 3 | 3 | 4 | 14 | 21 |
| 4 | 8 | 16 | 18 | 42 |
| 5 | 4 | 9 | 10 | 23 |
| 6 | 5 | 15 | 15 | 35 |
| 7 | 5 | 8 | 7 | 20 |
| 8 | 3 | 7 | 7 | 17 |
| 9 | | 3 | 3 | 6 |
| 70 | | 2 | | 2 |
| 1 | 1 | 2 | | 3 |
| 2 | 1 | 1 | | 2 |
| 3 | | 2 | | 2 |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | 1 | | | 1 |
| 9 | | | 1 | 1 |
| 80 | 1 | | 1 | 2 |
| 1 | | 1 | | 1 |
| 2 | | 1 | | 1 |
| 3 | 1 | 1 | | 2 |
| 4 | | | 1 | 1 |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | 1 | | | 1 |
| 9 | 2 | | | 2 |
| 90 | | | | |
| TOTAL | 200 | 100 | 100 | |
| Samples | 2 | 1 | 1 | |

1/ Shipped from Newport.

Table 45
Albacore Length Frequencies
Astoria--October 1953

| Length (cm) | Area 34-125 | Not Assigned 1/ | Total |
|---|---|---|---|
| 50 | | | |
| 1 | | 2 | 2 |
| 2 | | 4 | 4 |
| 3 | | 17 | 17 |
| 4 | | 23 | 23 |
| 5 | | 16 | 16 |
| 6 | | 18 | 18 |
| 7 | | 5 | 5 |
| 8 | | 3 | 3 |
| 9 | 1 | 1 | 2 |
| 60 | 2 | 2 | 4 |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | 1 | 1 |
| 5 | 2 | 3 | 5 |
| 6 | 3 | 1 | 4 |
| 7 | 4 | 1 | 5 |
| 8 | 4 | 2 | 6 |
| 9 | 2 | 1 | 3 |
| 70 | 2 | | 2 |
| I | 3 | | 3 |
| 2 | | | |
| 3 | 2 | | 2 |
| 4 | 4 | | 4 |
| 5 | | | |
| 6 | 3 | | 3 |
| 7 | | | |
| 8 | 3 | | 3 |
| 9 | 4 | | 4 |
| 80 | 2 | | 2 |
| I | 2 | | 2 |
| 2 | 2 | | 2 |
| 3 | 5 | | 5 |
| 4 | 2 | | 2 |
| 5 | 2 | | 2 |
| 6 | 2 | | 2 |
| 7 | 3 | | 3 |
| 8 | 1 | | 1 |
| 9 | | | |
| 90 | | | |
| 1 | 1 | | 1 |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | 1 | | 1 |
| TOTAL | 62 | 100 | |
| Samples | 1 | 1 | |

1/ Shipped from Newport.

Table 46
Albacore Length Frequencies
Astoria--September 1954

| Length (cm) | Area | | Total |
|---|---|---|---|
| | 33-120 | South of Pt. Delgada | |
| 50 | | | |
| 1 | 8 | 4 | 12 |
| 2 | 26 | 5 | 31 |
| 3 | 26 | 4 | 30 |
| 4 | 26 | 4 | 30 |
| 5 | 15 | 3 | 18 |
| 6 | 5 | 3 | 8 |
| 7 | 7 | 2 | 9 |
| 8 | 7 | 2 | 9 |
| 9 | 4 | 2 | 6 |
| 60 | 2 | | 2 |
| 1 | 6 | 2 | 8 |
| 2 | 2 | | 2 |
| 3 | 3 | 2 | 5 |
| 4 | 4 | 5 | 9 |
| 5 | 8 | 6 | 14 |
| 6 | 9 | 10 | 19 |
| 7 | 11 | 5 | 16 |
| 8 | 11 | 4 | 15 |
| 9 | 6 | 3 | 9 |
| 70 | 8 | 4 | 12 |
| 1 | 1 | 1 | 2 |
| 2 | | | |
| 3 | 1 | | 1 |
| 4 | | | |
| 5 | 2 | | 2 |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 80 | | | |
| 1 | 1 | 1 | 2 |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | 1 | | 1 |
| 8 | | | |
| 9 | | | |
| 90 | | | |
| TOTAL | 200 | 72 | |
| Samples | 1 | 1 | |

Table 47
Albacore Length Frequencies
Astoria--October 1954

| Length (cm) | Area: South of Pt. Delgada |
|---|---|
| 50 | 1 |
| 1 | |
| 2 | 3 |
| 3 | 5 |
| 4 | 4 |
| 5 | 5 |
| 6 | 4 |
| 7 | 3 |
| 8 | 4 |
| 9 | 2 |
| 60 | 1 |
| 1 | 1 |
| 2 | 2 |
| 3 | 2 |
| 4 | 6 |
| 5 | 8 |
| 6 | 16 |
| 7 | 11 |
| 8 | 12 |
| 9 | 6 |
| 70 | 5 |
| 1 | |
| 2 | |
| 3 | 1 |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | 1 |
| 9 | 1 |
| 80 | |
| 1 | |
| 2 | |
| 3 | 1 |
| 4 | 1 |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 106 |
| Samples | 1 |

Table 48
Albacore Length Frequencies
Astoria--September 1955

| Length (cm) | Area | | | Total |
|---|---|---|---|---|
| | 36-124 | 31-122 | South of Pt. Delgada | |
| 50 | | | | |
| 1 | | 2 | | 2 |
| 2 | | 1 | 3 | 4 |
| 3 | | 2 | 3 | 5 |
| 4 | | 5 | 3 | 8 |
| 5 | | 1 | | 1 |
| 6 | 2 | 2 | | 4 |
| 7 | 1 | 1 | | 2 |
| 8 | | 6 | 1 | 7 |
| 9 | 1 | 16 | 9 | 26 |
| 60 | 6 | 26 | 5 | 37 |
| 1 | 14 | 40 | 16 | 70 |
| 2 | 21 | 45 | 25 | 91 |
| 3 | 24 | 28 | 10 | 62 |
| 4 | 15 | 10 | 10 | 35 |
| 5 | 6 | 7 | 5 | 18 |
| 6 | 4 | 3 | 4 | 11 |
| 7 | | | | |
| 8 | 1 | | 1 | 2 |
| 9 | 2 | | 1 | 3 |
| 70 | 2 | 1 | 2 | 5 |
| 1 | 1 | | | 1 |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | 1 | 1 |
| 6 | | | | |
| 7 | | | | |
| 8 | | 2 | 1 | 3 |
| 9 | | | | |
| 80 | | 2 | | 2 |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | | | | |
| TOTAL | 100 | 200 | 100 | |
| Samples | 1 | 2 | 1 | |

Table 49
Albacore Length Frequencies
Astoria--September and October 1955

| Length (cm) | Not Assigned 1/ |
|---|---|
| 50 | |
| 1 | |
| 2 | 6 |
| 3 | 14 |
| 4 | 10 |
| 5 | 18 |
| 6 | 7 |
| 7 | 3 |
| 8 | 4 |
| 9 | 20 |
| 60 | 51 |
| 1 | 96 |
| 2 | 110 |
| 3 | 100 |
| 4 | 88 |
| 5 | 24 |
| 6 | 14 |
| 7 | 9 |
| 8 | 3 |
| 9 | 1 |
| 70 | 3 |
| 1 | 1 |
| 2 | 3 |
| 3 | |
| 4 | 2 |
| 5 | 1 |
| 6 | 3 |
| 7 | |
| 8 | 3 |
| 9 | 1 |
| 80 | 1 |
| 1 | 1 |
| 2 | 1 |
| 3 | 2 |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 600 |
| Samples | 6 |

1/ Shipped from San Francisco.

Table 50
Albacore Length Frequencies
Astoria--October 1955

| Length (cm) | Area | | | | Total |
|---|---|---|---|---|---|
| | 36-125 | 37-125 | 35-124 | 36-124 | |
| 50 | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | 2 | | 6 | 3 | 11 |
| 4 | 2 | 1 | 2 | 2 | 7 |
| 5 | 2 | | 5 | | 7 |
| 6 | 4 | | | 1 | 5 |
| 7 | 1 | | | 2 | 3 |
| 8 | 2 | | 5 | 2 | 9 |
| 9 | 2 | | 2 | 1 | 5 |
| 60 | 4 | 3 | 9 | 5 | 21 |
| 1 | 12 | 9 | 16 | 12 | 49 |
| 2 | 30 | 20 | 17 | 18 | 85 |
| 3 | 16 | 22 | 19 | 20 | 77 |
| 4 | 11 | 14 | 11 | 17 | 53 |
| 5 | 6 | 16 | 5 | 8 | 35 |
| 6 | 1 | 10 | | 4 | 15 |
| 7 | 2 | 3 | 1 | 1 | 7 |
| 8 | | 1 | | 2 | 3 |
| 9 | | 1 | | | 1 |
| 70 | 1 | | | | 1 |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | 1 | 1 |
| 8 | 1 | | | | 1 |
| 9 | | | 1 | | 1 |
| 80 | 1 | | | | 1 |
| 1 | | | 1 | 1 | 2 |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 100 | 100 | 100 | 100 | |
| Samples | 1 | 1 | 1 | 1 | |

Table 51
Albacore Length Frequencies
Astoria--August 1956

| Length (cm) | Area 44-126 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | 1 |
| 7 | 1 |
| 8 | |
| 9 | |
| 60 | 1 |
| 1 | 1 |
| 2 | |
| 3 | 2 |
| 4 | 1 |
| 5 | 12 |
| 6 | 9 |
| 7 | 8 |
| 8 | 7 |
| 9 | 6 |
| 70 | 4 |
| 1 | 3 |
| 2 | 2 |
| 3 | 7 |
| 4 | 9 |
| 5 | 10 |
| 6 | 8 |
| 7 | 3 |
| 8 | 4 |
| 9 | |
| 80 | 1 |
| TOTAL | 100 |
| Samples | 1 |

Table 52
Albacore Length Frequencies
Tagged & Released at Sea--August 1956

| Length (cm) | Area North of Pt. Delgada |
|---|---|
| 50 | |
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |
| 4 | |
| 5 | 2 |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 60 | |
| 1 | 2 |
| 2 | 1 |
| 3 | 1 |
| 4 | 8 |
| 5 | 11 |
| 6 | 9 |
| 7 | 11 |
| 8 | 7 |
| 9 | 3 |
| 70 | 1 |
| 1 | 1 |
| 2 | |
| 3 | 3 |
| 4 | 1 |
| 5 | 5 |
| 6 | 1 |
| 7 | |
| 8 | |
| 9 | |
| 80 | |
| TOTAL | 70 |
| Samples | 2 |

Table 53
Albacore Length Frequencies
Astoria--September 1956

| Length (cm) | Area | | | | Total |
|---|---|---|---|---|---|
| | 45-126 | 45-49-125-129 | 44-126 | 44-127 | |
| 50 | | | | | |
| 1 | | | | 2 | 2 |
| 2 | 2 | | | 1 | 3 |
| 3 | 3 | 1 | 2 | 1 | 7 |
| 4 | 7 | 2 | | 2 | 11 |
| 5 | 3 | 6 | 4 | 3 | 16 |
| 6 | 4 | 1 | 1 | 1 | 7 |
| 7 | 7 | 2 | 1 | | 10 |
| 8 | | 4 | 1 | | 5 |
| 9 | 1 | 1 | 1 | | 3 |
| 60 | 1 | | 2 | 1 | 4 |
| 1 | 1 | | 5 | 1 | 7 |
| 2 | 10 | 4 | 17 | 6 | 37 |
| 3 | 15 | 5 | 28 | 5 | 53 |
| 4 | 26 | 10 | 40 | 13 | 89 |
| 5 | 44 | 15 | 31 | 18 | 108 |
| 6 | 51 | 19 | 33 | 15 | 118 |
| 7 | 50 | 14 | 22 | 14 | 100 |
| 8 | 32 | 3 | 3 | 6 | 44 |
| 9 | 19 | 4 | 2 | 4 | 29 |
| 70 | 8 | 2 | | | 10 |
| 1 | 4 | 1 | 1 | | 6 |
| 2 | 2 | 2 | 3 | 1 | 8 |
| 3 | 2 | | 2 | | 4 |
| 4 | | | 1 | 1 | 2 |
| 5 | 1 | 1 | | 1 | 3 |
| 6 | 3 | | | 3 | 6 |
| 7 | 1 | | | 1 | 2 |
| 8 | 1 | 1 | | | 2 |
| 9 | | 2 | | | 2 |
| 80 | 1 | | | | 1 |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | 1 | | | | 1 |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 300 | 100 | 200 | 100 | |
| Samples | 3 | 1 | 2 | 1 | |

Table 54
Albacore Length Frequencies
Newport--August 1956

| Length (cm) | 5° Area 45-49-125-129 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | 2 |
| 5 | 2 |
| 6 | 4 |
| 7 | 2 |
| 8 | 1 |
| 9 | |
| 60 | |
| 1 | 1 |
| 2 | |
| 3 | 3 |
| 4 | 8 |
| 5 | 16 |
| 6 | 24 |
| 7 | 16 |
| 8 | 6 |
| 9 | 5 |
| 70 | 4 |
| 1 | |
| 2 | 2 |
| 3 | 1 |
| 4 | 1 |
| 5 | 1 |
| 6 | |
| 7 | 1 |
| 8 | |
| 9 | |
| 80 | |
| TOTAL | 100 |
| Samples | 1 |

Table 55
Albacore Length Frequencies
Newport--September 1956

| Length (cm) | Area 45-49-125-129 | 43-125 | 44-126 | Total |
|---|---|---|---|---|
| 50 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | 1 | | 1 | 2 |
| 6 | | 1 | | 1 |
| 7 | | 2 | | 2 |
| 8 | 1 | 3 | | 4 |
| 9 | | | | |
| 60 | | | 1 | 1 |
| 1 | | 1 | 1 | 2 |
| 2 | 2 | 2 | 2 | 6 |
| 3 | 5 | 2 | 4 | 11 |
| 4 | 8 | 8 | 10 | 26 |
| 5 | 18 | 14 | 12 | 44 |
| 6 | 25 | 16 | 20 | 61 |
| 7 | 17 | 18 | 23 | 58 |
| 8 | 13 | 13 | 11 | 37 |
| 9 | 7 | 8 | 5 | 20 |
| 70 | 1 | 4 | 5 | 10 |
| 1 | 1 | | | 1 |
| 2 | | 1 | | 1 |
| 3 | | 1 | 1 | 2 |
| 4 | 1 | 2 | | 3 |
| 5 | | | 1 | 1 |
| 6 | | 2 | 2 | 4 |
| 7 | | 1 | 1 | 2 |
| 8 | | 1 | | 1 |
| 9 | | | | |
| 80 | | | | |
| TOTAL | 100 | 100 | 100 | |
| Samples | 1 | 1 | 1 | |

Table 56
Albacore Length Frequencies
Astoria--August 1957

| Length (cm) | Area | | | | | | | | Not Assigned | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 46-125 | 47-125 | 45-49-125-129 | 45-124 | 46-124 | 45-49-120-124 | 40-44-125-129 | North of Pt. Delgada | | |
| 50 | 1 | | | 1 | | | | | | 2 |
| 1 | 1 | | | 2 | 2 | | | | | 5 |
| 2 | | | | 9 | 7 | 2 | | | | 18 |
| 3 | 2 | 2 | | 14 | 24 | 1 | | 1 | | 44 |
| 4 | 3 | | | 12 | 23 | 4 | | 2 | 1 | 45 |
| 5 | 1 | 2 | | 8 | 33 | 2 | | | | 46 |
| 6 | | | | 5 | 15 | 3 | | 1 | | 24 |
| 7 | | 3 | 1 | 3 | 9 | 5 | | 1 | | 22 |
| 8 | | 3 | 1 | 5 | 8 | 1 | 1 | | 1 | 20 |
| 9 | 2 | 5 | | 6 | 18 | 2 | 2 | 1 | 4 | 40 |
| 60 | 4 | 3 | 1 | 4 | 8 | 7 | | 1 | 5 | 33 |
| 1 | 3 | 7 | 6 | 9 | 21 | 9 | 3 | 6 | 5 | 69 |
| 2 | 10 | 19 | 6 | 9 | 37 | 9 | 14 | 3 | 6 | 113 |
| 3 | 23 | 41 | 15 | 15 | 77 | 40 | 12 | 10 | 12 | 245 |
| 4 | 30 | 66 | 25 | 27 | 128 | 56 | 13 | 17 | 15 | 377 |
| 5 | 28 | 78 | 36 | 39 | 140 | 63 | 13 | 35 | 17 | 449 |
| 6 | 24 | 43 | 46 | 23 | 98 | 34 | 10 | 19 | 13 | 310 |
| 7 | 11 | 30 | 33 | 9 | 37 | 7 | 3 | 11 | 11 | 152 |
| 8 | 3 | 8 | 10 | 4 | 14 | 6 | 1 | 2 | | 48 |
| 9 | 3 | 7 | 6 | 1 | 4 | | 2 | | 3 | 26 |
| 70 | 2 | 2 | 1 | 1 | 1 | | 2 | 2 | | 11 |
| 1 | 1 | 2 | 5 | 1 | | | 1 | 1 | | 11 |
| 2 | 5 | 3 | 7 | 1 | | 2 | 2 | 2 | 1 | 23 |
| 3 | 13 | 2 | 9 | 2 | 1 | 1 | 2 | 2 | 2 | 34 |
| 4 | 28 | 1 | 17 | 5 | 8 | 2 | 2 | 3 | 1 | 67 |
| 5 | 30 | 8 | 15 | 6 | 11 | 2 | 2 | 4 | | 78 |
| 6 | 46 | 5 | 25 | 10 | 14 | | 3 | 3 | | 106 |
| 7 | 25 | 1 | 16 | 8 | 18 | | 5 | 5 | 1 | 79 |
| 8 | 17 | 2 | 16 | 8 | 9 | 4 | 4 | 6 | 2 | 68 |
| 9 | 12 | 1 | 6 | 7 | 4 | | | 5 | | 35 |
| 80 | 7 | 2 | 5 | | 5 | 1 | 2 | 3 | | 25 |
| 1 | 5 | 2 | | 1 | 2 | 1 | 1 | 3 | | 15 |
| 2 | 1 | 2 | 1 | 3 | | | | 1 | | 8 |
| 3 | 2 | | | 1 | | | | | | 3 |
| 4 | | | | | 1 | | | | | 1 |
| 5 | | | | 1 | | | | | | 1 |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 90 | | | | | | | | | | |
| TOTAL | 343 | 350 | 309 | 260 | 777 | 264 | 100 | 150 | 100 | |
| Samples | 4 | 3 | 3 | 3 | 6 | 3 | 1 | 2 | 1 | |

Table 57
Albacore Length Frequencies
Astoria--September 1957

| Length (cm) | Area 47-125 | Area 40-125 | Area 42-125 | Not Assigned | Total |
|---|---|---|---|---|---|
| 50 | | | | | |
| 1 | | | | 1 | 1 |
| 2 | | | 3 | 8 | 11 |
| 3 | 6 | | 6 | 17 | 29 |
| 4 | 8 | | 7 | 14 | 29 |
| 5 | 4 | 1 | 5 | 9 | 19 |
| 6 | 4 | 1 | 9 | 8 | 22 |
| 7 | 8 | 1 | 1 | 3 | 13 |
| 8 | 13 | | 5 | 1 | 19 |
| 9 | 13 | 3 | 1 | 1 | 18 |
| 60 | 22 | 2 | 6 | 3 | 33 |
| 1 | 25 | 2 | 7 | 3 | 37 |
| 2 | 47 | 10 | 5 | 5 | 67 |
| 3 | 80 | 19 | 11 | 8 | 118 |
| 4 | 142 | 46 | 18 | 6 | 212 |
| 5 | 205 | 76 | 27 | 22 | 330 |
| 6 | 204 | 74 | 37 | 15 | 330 |
| 7 | 142 | 39 | 28 | 10 | 219 |
| 8 | 53 | 14 | 14 | 2 | 83 |
| 9 | 30 | 10 | 2 | 3 | 45 |
| 70 | 7 | | 2 | 1 | 10 |
| 1 | 6 | 1 | | | 2 |
| 2 | 5 | 2 | 1 | 1 | 9 |
| 3 | 4 | 1 | | 1 | 6 |
| 4 | 6 | 2 | | 1 | 9 |
| 5 | 14 | 2 | 1 | 3 | 20 |
| 6 | 17 | 3 | | 3 | 23 |
| 7 | 15 | 3 | 3 | 4 | 25 |
| 8 | 17 | 3 | 2 | 2 | 24 |
| 9 | 14 | 5 | 1 | 4 | 24 |
| 80 | 8 | 3 | | 2 | 13 |
| 1 | 10 | 4 | 1 | 1 | 16 |
| 2 | 3 | | | | 3 |
| 3 | 1 | | | 1 | 2 |
| 4 | | | | 1 | 1 |
| 5 | 1 | | | | 1 |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 1,134 | 327 | 203 | 164 | |
| Samples | 6 | 1 | 1 | 1 | |

Table 58
Albacore Length Frequencies
Astoria--October 1957

| Length (cm) | Area | | | Total |
|---|---|---|---|---|
| | 41-125 | 42-125 | 40-44-125-129 | |
| 50 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | 1 | 1 |
| 7 | | | | |
| 8 | | | 1 | 1 |
| 9 | | | 2 | 2 |
| 60 | | | 7 | 7 |
| 1 | 1 | 2 | 11 | 14 |
| 2 | 1 | 2 | 14 | 17 |
| 3 | 5 | 3 | 10 | 18 |
| 4 | 10 | 5 | 20 | 35 |
| 5 | 11 | 11 | 28 | 50 |
| 6 | 16 | 19 | 35 | 70 |
| 7 | 8 | 21 | 18 | 47 |
| 8 | 10 | 7 | 9 | 26 |
| 9 | 6 | 8 | 8 | 22 |
| 70 | 1 | 2 | 2 | 5 |
| 1 | | 1 | | 1 |
| 2 | 1 | | | 1 |
| 3 | | | | |
| 4 | 1 | | | 1 |
| 5 | | | | |
| 6 | 1 | | | 1 |
| 7 | 2 | | | 2 |
| 8 | 1 | 1 | | 2 |
| 9 | 3 | | | 3 |
| 80 | | | 1 | 1 |
| 1 | | 2 | | 2 |
| 2 | 2 | | | 2 |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | | | | |
| TOTAL | 80 | 84 | 167 | |
| Samples | 1 | 1 | 1 | |

Table 59
Albacore Length Frequencies
Newport--July and August 1957

| Length (cm) | July Area 47-126 | August Area 45-124 | August Area 44-124 | Total |
|---|---|---|---|---|
| 50 | | | | |
| 1 | 1 | | | 1 |
| 2 | | | | |
| 3 | | 7 | 1 | 8 |
| 4 | | 2 | 1 | 3 |
| 5 | | 2 | | 2 |
| 6 | | 1 | 1 | 2 |
| 7 | | 3 | | 3 |
| 8 | 1 | | 2 | 3 |
| 9 | 1 | 3 | 1 | 5 |
| 60 | | 7 | 5 | 12 |
| 1 | 3 | 6 | 5 | 14 |
| 2 | 8 | 26 | 4 | 38 |
| 3 | 8 | 47 | 21 | 76 |
| 4 | 24 | 57 | 26 | 107 |
| 5 | 26 | 57 | 39 | 122 |
| 6 | 18 | 63 | 36 | 117 |
| 7 | 6 | 30 | 26 | 62 |
| 8 | | 19 | 7 | 26 |
| 9 | 1 | 9 | 2 | 12 |
| 70 | | 2 | 1 | 3 |
| 1 | | 3 | 2 | 5 |
| 2 | 1 | 5 | | 6 |
| 3 | 1 | 7 | 1 | 9 |
| 4 | 1 | 18 | 8 | 27 |
| 5 | | 20 | 3 | 23 |
| 6 | | 25 | 9 | 34 |
| 7 | | 37 | 13 | 50 |
| 8 | | 35 | 11 | 46 |
| 9 | | 17 | 6 | 23 |
| 80 | | 8 | 10 | 18 |
| 1 | | 9 | 2 | 11 |
| 2 | | 3 | 2 | 5 |
| 3 | | 2 | | 2 |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | | | | |
| TOTAL | 100 | 530 | 245 | |
| Samples | 1 | 6 | 3 | |

Table 60
Albacore Length Frequencies
Newport--September 1957

| Length (cm) | Area 40-125 | Area 41-125 | Total |
|---|---|---|---|
| 50 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | 1 | 1 |
| 6 | 1 | | 1 |
| 7 | | | |
| 8 | 1 | 1 | 2 |
| 9 | 1 | 3 | 4 |
| 60 | 2 | 2 | 4 |
| 1 | 3 | 4 | 7 |
| 2 | 9 | 5 | 14 |
| 3 | 10 | 11 | 21 |
| 4 | 11 | 13 | 24 |
| 5 | 25 | 20 | 45 |
| 6 | 26 | 15 | 41 |
| 7 | 11 | 8 | 19 |
| 8 | 1 | 4 | 5 |
| 9 | 1 | 4 | 5 |
| 70 | | 1 | 1 |
| 1 | | 1 | 1 |
| 2 | | | |
| 3 | | | |
| 4 | | 1 | 1 |
| 5 | | | |
| 6 | 1 | 2 | 3 |
| 7 | 1 | | 1 |
| 8 | | | |
| 9 | | 3 | 3 |
| 80 | | 1 | 1 |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 90 | | | |
| TOTAL | 104 | 100 | |
| Samples | 1 | 1 | |

Table 61
Albacore Length Frequencies
Tagged & Released at Sea--July 1957

| Length (cm) | Area | | Total |
|---|---|---|---|
| | 40-44-125-129 | 40-44-130-134 | |
| 50 | | | |
| 1 | | | |
| 2 | 1 | | 1 |
| 3 | | | |
| 4 | 4 | 7 | 11 |
| 5 | 4 | 1 | 5 |
| 6 | 1 | 1 | 2 |
| 7 | 2 | | 2 |
| 8 | | | |
| 9 | 1 | | 1 |
| 60 | 1 | | 1 |
| 1 | 3 | | 3 |
| 2 | 1 | | 1 |
| 3 | 6 | | 6 |
| 4 | 18 | 1 | 19 |
| 5 | 19 | | 19 |
| 6 | 15 | | 15 |
| 7 | 4 | | 4 |
| 8 | 3 | | 3 |
| 9 | 2 | | 2 |
| 70 | | | |
| 1 | 1 | | 1 |
| 2 | | | |
| 3 | | | |
| 4 | 1 | | 1 |
| 5 | 1 | | 1 |
| 6 | | 1 | 1 |
| 7 | | | |
| 8 | 2 | | 2 |
| 9 | 1 | | 1 |
| 80 | | | |
| TOTAL | 91 | 11 | |
| Samples | 1 | 1 | |

Table 62
Albacore Length Frequencies
Astoria--July 1958

| Length (cm) | Area | | | | | Total |
|---|---|---|---|---|---|---|
| | 45-125 | 43-126 | 44-127 | 40-44-125-129 | 34-122 | |
| 50 | | | | 1 | | 1 |
| 1 | | | | | | |
| 2 | | | 4 | 4 | | 8 |
| 3 | | | 2 | 1 | | 3 |
| 4 | | | 1 | 1 | | 2 |
| 5 | | | 1 | 1 | 1 | 3 |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | 1 | | | 1 |
| 9 | | | 3 | 1 | 1 | 5 |
| 60 | | 3 | 2 | 1 | 4 | 10 |
| 1 | | 3 | 5 | 6 | 1 | 15 |
| 2 | 3 | 3 | 7 | 6 | 3 | 22 |
| 3 | 4 | 8 | 8 | 10 | 4 | 34 |
| 4 | 2 | 13 | 13 | 18 | 4 | 50 |
| 5 | 8 | 25 | 42 | 19 | 3 | 97 |
| 6 | 11 | 25 | 33 | 28 | 10 | 107 |
| 7 | 6 | 24 | 37 | 20 | 7 | 94 |
| 8 | 7 | 16 | 19 | 13 | 8 | 63 |
| 9 | 6 | 12 | 10 | 10 | 1 | 39 |
| 70 | 2 | 9 | 6 | 11 | | 28 |
| 1 | | 4 | 1 | 3 | 3 | 11 |
| 2 | | 1 | 2 | | | 3 |
| 3 | | 1 | 1 | | | 2 |
| 4 | | | | | | |
| 5 | | | 1 | | | 1 |
| 6 | | | | | | |
| 7 | | 1 | 1 | 1 | | 3 |
| 8 | | | | 1 | | 1 |
| 9 | 1 | | | | | 1 |
| 80 | | | | 1 | | 1 |
| 1 | | 1 | | | | 1 |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 90 | | | | | | |
| TOTAL | 50 | 149 | 200 | 157 | 50 | |
| Samples | 1 | 2 | 3 | 2 | 1 | |

Table 63
Albacore Length Frequencies
Astoria--August 1958

| Length (cm) | Area | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | 45-125 | 45-126 | 46-125 | 47-125 | 47-126 | 40-124 | 44-126 | North of Pt. Delgada | |
| 50 | | | | | | | | | |
| 1 | | | | 1 | | | | | 1 |
| 2 | | | | 2 | | | | 5 | 7 |
| 3 | | | 1 | 4 | 1 | | | 2 | 8 |
| 4 | | | 1 | | | | 1 | 1 | 3 |
| 5 | | | | 2 | | | | 1 | 3 |
| 6 | | | | | | | | 1 | 1 |
| 7 | | | | | | | | 1 | 1 |
| 8 | | | | | | | | 1 | 1 |
| 9 | | | 1 | 2 | | | 1 | 2 | 6 |
| 60 | | 4 | | | 1 | | 6 | 1 | 12 |
| 1 | | 6 | 1 | 1 | | | 1 | 4 | 13 |
| 2 | | 3 | | 6 | 1 | | 2 | 7 | 19 |
| 3 | 5 | 8 | 3 | 10 | 5 | | 8 | 11 | 50 |
| 4 | 7 | 20 | 6 | 3 | 8 | | 7 | 12 | 63 |
| 5 | 7 | 26 | 7 | 15 | 6 | | 13 | 17 | 91 |
| 6 | 21 | 21 | 5 | 17 | 5 | 1 | 17 | 14 | 101 |
| 7 | 9 | 22 | 8 | 26 | 7 | 2 | 16 | 20 | 110 |
| 8 | 8 | 19 | 8 | 19 | 7 | 1 | 13 | 10 | 85 |
| 9 | 13 | 12 | 3 | 7 | 4 | 5 | 6 | 15 | 65 |
| 70 | 6 | 6 | 4 | 10 | 1 | 7 | 6 | 10 | 50 |
| 1 | 4 | 4 | | 5 | 1 | 3 | 1 | 6 | 24 |
| 2 | 3 | | | 3 | | | | 1 | 7 |
| 3 | 2 | | 1 | 3 | | 2 | | | 8 |
| 4 | 1 | | 1 | | | 1 | | | 3 |
| 5 | 1 | 1 | | | | | | | 2 |
| 6 | 6 | | | | | 1 | | 1 | 8 |
| 7 | 8 | | | 1 | 1 | 1 | | | 11 |
| 8 | 6 | | | 5 | | 6 | | | 17 |
| 9 | 9 | 1 | | 2 | 1 | 7 | | 1 | 21 |
| 80 | 9 | | | 1 | | 6 | 2 | 1 | 19 |
| 1 | 6 | | | 3 | | 2 | | 1 | 12 |
| 2 | 6 | 1 | | 3 | 1 | 4 | | 2 | 17 |
| 3 | 7 | | | | | | | 1 | 8 |
| 4 | 4 | | | | | | | 1 | 5 |
| 5 | 2 | | | | | 1 | | | 3 |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 90 | | | | | | | | | |
| TOTAL | 150 | 154 | 50 | 151 | 50 | 50 | 100 | 150 | |
| Samples | 3 | 3 | 1 | 3 | 1 | 1 | 2 | 3 | |

Table 64
Albacore Length Frequencies
Astoria--September 1958

| Length (cm) | Area | | | | Total |
|---|---|---|---|---|---|
| | 45-125 | 41-125 | 42-126 | 44-125 | |
| 50 | | | | | |
| 1 | 1 | | | | 1 |
| 2 | 2 | | | | 2 |
| 3 | 12 | 1 | | | 13 |
| 4 | 36 | 3 | 2 | | 41 |
| 5 | 51 | 3 | 10 | | 64 |
| 6 | 37 | 1 | 9 | | 47 |
| 7 | 22 | | | | 22 |
| 8 | 8 | | 1 | | 9 |
| 9 | 2 | | | | 2 |
| 60 | 1 | | 1 | | 2 |
| 1 | 2 | | | | 2 |
| 2 | 7 | | 1 | | 8 |
| 3 | 11 | 1 | 7 | | 19 |
| 4 | 16 | 2 | 8 | 5 | 31 |
| 5 | 24 | 7 | 16 | 1 | 48 |
| 6 | 36 | 5 | 13 | 4 | 58 |
| 7 | 49 | 5 | 27 | 6 | 87 |
| 8 | 42 | 5 | 16 | 8 | 71 |
| 9 | 55 | 6 | 11 | 10 | 82 |
| 70 | 31 | 3 | 7 | 2 | 43 |
| 1 | 24 | 2 | 8 | 3 | 37 |
| 2 | 8 | 2 | 3 | 7 | 20 |
| 3 | 6 | | 2 | 1 | 9 |
| 4 | 1 | | | | 1 |
| 5 | | | | | |
| 6 | 2 | | | | 2 |
| 7 | 1 | 1 | | | 2 |
| 8 | | | 1 | | 1 |
| 9 | 5 | | | | 5 |
| 80 | 7 | | 1 | | 8 |
| 1 | 7 | 1 | | 1 | 9 |
| 2 | 3 | 1 | 2 | 1 | 7 |
| 3 | 3 | 1 | 1 | | 5 |
| 4 | 4 | | 2 | 1 | 7 |
| 5 | 4 | | | | 4 |
| 6 | | | 1 | | 1 |
| 7 | 1 | | | | 1 |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 521 | 50 | 150 | 50 | |
| Samples | 9 | 1 | 3 | 1 | |

Table 65
Albacore Length Frequencies
Astoria--October 1958

| Length (cm) | Area | | | Total |
|---|---|---|---|---|
| | 45-125 | 48-125 | 46-124 | |
| 50 | | | | |
| 1 | | | | |
| 2 | 1 | | | 1 |
| 3 | 2 | 2 | | 4 |
| 4 | 2 | 3 | | 5 |
| 5 | 7 | | 1 | 8 |
| 6 | 2 | | | 2 |
| 7 | 2 | 2 | | 4 |
| 8 | 2 | | | 2 |
| 9 | | | | |
| 60 | | | | |
| 1 | | | 1 | 1 |
| 2 | 1 | | | 1 |
| 3 | | 1 | | 1 |
| 4 | 1 | 2 | 2 | 5 |
| 5 | 5 | 2 | 2 | 9 |
| 6 | 7 | 3 | 6 | 16 |
| 7 | 10 | 3 | 5 | 18 |
| 8 | 11 | 5 | 10 | 26 |
| 9 | 8 | 9 | 3 | 20 |
| 70 | 8 | 7 | 7 | 22 |
| 1 | 5 | 3 | 4 | 12 |
| 2 | 5 | 2 | 1 | 8 |
| 3 | 1 | | | 1 |
| 4 | 3 | | | 3 |
| 5 | | | 1 | 1 |
| 6 | | 1 | | 1 |
| 7 | 1 | | | 1 |
| 8 | 4 | 2 | 1 | 7 |
| 9 | 2 | | | 2 |
| 80 | | 1 | 2 | 3 |
| 1 | 1 | | 1 | 2 |
| 2 | 2 | 1 | 1 | 4 |
| 3 | 3 | 1 | | 4 |
| 4 | 2 | | 2 | 4 |
| 5 | 1 | | | 1 |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | 1 | | | 1 |
| TOTAL | 100 | 50 | 50 | |
| Samples | 2 | 1 | 1 | |

Table 66
Albacore Length Frequencies
Newport--August 1958

| Length (cm) | Area 44-126 |
|---|---|
| 60 | |
| 1 | 1 |
| 2 | 3 |
| 3 | 3 |
| 4 | 3 |
| 5 | 4 |
| 6 | 12 |
| 7 | 12 |
| 8 | 4 |
| 9 | 5 |
| 70 | 1 |
| 1 | |
| 2 | 1 |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 80 | |
| 1 | |
| 2 | 1 |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 50 |
| Samples | 1 |

Table 67
Albacore Length Frequencies
Astoria--July 1959

| Length (cm) | Area | | Total |
|---|---|---|---|
| | 45-125 | North of Pt. Delgada | |
| 60 | | | |
| 1 | | 1 | 1 |
| 2 | 1 | 1 | 2 |
| 3 | 7 | 5 | 12 |
| 4 | 21 | 23 | 44 |
| 5 | 35 | 19 | 54 |
| 6 | 26 | 22 | 48 |
| 7 | 18 | 14 | 32 |
| 8 | 13 | 8 | 21 |
| 9 | 3 | 3 | 6 |
| 70 | 1 | | 1 |
| 1 | 3 | | 3 |
| 2 | | | |
| 3 | 1 | | 1 |
| 4 | | | |
| 5 | 3 | | 3 |
| 6 | | | |
| 7 | 6 | | 6 |
| 8 | 5 | | 5 |
| 9 | 1 | 1 | 2 |
| 80 | 2 | | 2 |
| 1 | | 2 | 2 |
| 2 | | 1 | 1 |
| 3 | 2 | | 2 |
| 4 | 1 | | 1 |
| 5 | 1 | | 1 |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 90 | | | |
| TOTAL | 150 | 100 | |
| Samples | 3 | 2 | |

Table 68
Albacore Length Frequencies
Astoria--August 1959

| Length (cm) | Area | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | 45-125 | 45-126 | 46-125 | 47-125 | 45-49-125-129 | 41-125 | 44-126 | 40-44-125-129 | |
| 50 | | | | | | | | | |
| 1 | | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | 1 | | | | | | | 1 |
| 4 | | | 1 | | | | | | 1 |
| 5 | | | 3 | | | | | | 3 |
| 6 | 1 | | | | | | | 1 | 2 |
| 7 | | | | | | | | | |
| 8 | | | | | | | 1 | | 1 |
| 9 | | 1 | 1 | | | 1 | | 2 | 5 |
| 60 | | | | | | | | | |
| 1 | | | 1 | | 2 | | | | 3 |
| 2 | | 3 | 6 | 2 | 2 | 1 | 2 | 1 | 17 |
| 3 | | 3 | 12 | 4 | 16 | 2 | 3 | 1 | 41 |
| 4 | 6 | 8 | 36 | 10 | 31 | 5 | 6 | 8 | 110 |
| 5 | 16 | 7 | 67 | 21 | 58 | 3 | 8 | 10 | 190 |
| 6 | 11 | 11 | 94 | 21 | 56 | 12 | 18 | 13 | 236 |
| 7 | 9 | 7 | 65 | 26 | 32 | 14 | 7 | 7 | 167 |
| 8 | 2 | 7 | 31 | 8 | 20 | 6 | 1 | 5 | 80 |
| 9 | 3 | | 13 | 4 | 12 | 3 | | 2 | 37 |
| 70 | 1 | | 10 | | 3 | 2 | 1 | | 17 |
| 1 | | | 1 | | 2 | | 1 | | 4 |
| 2 | | | 1 | | | | | | 1 |
| 3 | | | 1 | | | | | | 1 |
| 4 | | | | | 1 | | | | 1 |
| 5 | | | | 1 | 1 | | | | 2 |
| 6 | | | | | 2 | | | | 2 |
| 7 | | | | 1 | 2 | 1 | 1 | | 5 |
| 8 | | | | 1 | 2 | | 1 | | 4 |
| 9 | | | 1 | | 3 | | | | 4 |
| 80 | | | 2 | | 2 | | | | 4 |
| 1 | | | 1 | | 3 | | | | 4 |
| 2 | 1 | 1 | 1 | | | | | | 3 |
| 3 | | | 2 | 1 | | | | | 3 |
| 4 | | 1 | | | | | | | 1 |
| 5 | | | | | | | | | |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 90 | | | | | | | | | |
| TOTAL | 50 | 50 | 350 | 100 | 250 | 50 | 50 | 50 | |
| Samples | 1 | 1 | 7 | 2 | 5 | 1 | 1 | 1 | |

Table 69
Albacore Length Frequencies
Astoria--September 1959

| Length (cm) | Area | | | | Total |
|---|---|---|---|---|---|
| | 45-125 | 46-125 | 45-49-125-129 | 44-125 | |
| 55 | 1 | 1 | | | 2 |
| 6 | 1 | 1 | 1 | | 3 |
| 7 | 1 | | 1 | | 2 |
| 8 | | 3 | 1 | | 4 |
| 9 | | 2 | 1 | | 3 |
| 60 | | | 2 | | 2 |
| 1 | | 5 | 4 | 1 | 10 |
| 2 | | 1 | 1 | | 2 |
| 3 | | 11 | 1 | | 12 |
| 4 | 7 | 8 | 7 | 1 | 23 |
| 5 | 12 | 13 | 7 | 3 | 35 |
| 6 | 18 | 15 | 7 | 8 | 48 |
| 7 | 26 | 16 | 7 | 4 | 53 |
| 8 | 16 | 10 | 3 | 4 | 33 |
| 9 | 10 | 10 | 3 | 4 | 27 |
| 70 | 1 | 4 | 3 | | 8 |
| 1 | 3 | | 1 | 1 | 5 |
| 2 | | | | 2 | 2 |
| 3 | | | | 1 | 1 |
| 4 | | | | 1 | 1 |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | 1 | | | | 1 |
| 9 | | | | 3 | 3 |
| 80 | 1 | | | 3 | 4 |
| 1 | | | | 2 | 2 |
| 2 | 1 | | | 3 | 4 |
| 3 | | | | 4 | 4 |
| 4 | | | | 2 | 2 |
| 5 | 1 | | | 1 | 2 |
| 6 | | | | 1 | 1 |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| 1 | | | | | |
| 2 | | | | 1 | 1 |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| TOTAL | 100 | 100 | 50 | 50 | |
| Samples | 2 | 2 | 1 | 1 | |

Table 70
Albacore Length Frequencies
Newport--July 1959

| Length (cm) | Area | | | | Total |
|---|---|---|---|---|---|
| | 45-125 | 45-49-125-129 | 44-125 | North of Pt. Delgada | |
| 50 | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | 1 | | 1 | | 2 |
| 9 | | | 1 | | 1 |
| 60 | 1 | | | | 1 |
| 1 | 1 | 1 | | | 2 |
| 2 | 2 | 6 | 1 | 4 | 13 |
| 3 | 19 | 17 | 3 | 3 | 42 |
| 4 | 17 | 25 | 8 | 17 | 67 |
| 5 | 29 | 47 | 10 | 31 | 117 |
| 6 | 30 | 39 | 10 | 16 | 95 |
| 7 | 22 | 27 | 5 | 9 | 63 |
| 8 | 8 | 19 | 2 | 7 | 36 |
| 9 | 3 | 6 | 1 | 5 | 15 |
| 70 | 1 | 2 | | 1 | 4 |
| 1 | 1 | 1 | | | 2 |
| 2 | | | | 1 | 1 |
| 3 | 1 | 1 | | 1 | 3 |
| 4 | | | 2 | | 2 |
| 5 | | | 2 | | 2 |
| 6 | | | 1 | | 1 |
| 7 | 2 | 1 | 1 | 1 | 5 |
| 8 | 1 | 1 | | | 2 |
| 9 | 2 | 6 | 2 | 1 | 11 |
| 80 | 3 | 1 | | | 4 |
| 1 | 2 | | | 1 | 3 |
| 2 | 3 | | | 1 | 4 |
| 3 | | | | | |
| 4 | 1 | | | | 1 |
| 5 | | | | 1 | 1 |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 90 | | | | | |
| TOTAL | 150 | 200 | 50 | 100 | |
| Samples | 3 | 4 | 1 | 2 | |

Table 71
Albacore Length Frequencies
Newport--August 1959

| Length (cm) | Area 45-125 |
|---|---|
| 50 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | 1 |
| 60 | 1 |
| 1 | 4 |
| 2 | 2 |
| 3 | 9 |
| 4 | 15 |
| 5 | 17 |
| 6 | 19 |
| 7 | 12 |
| 8 | 10 |
| 9 | 4 |
| 70 | |
| 1 | 1 |
| 2 | |
| 3 | |
| 4 | |
| 5 | 1 |
| 6 | |
| 7 | |
| 8 | 1 |
| 9 | 1 |
| 80 | 1 |
| 1 | |
| 2 | 1 |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 100 |
| Samples | 2 |

Table 72
Albacore Length Frequencies
Coos Bay--July 1959

| Length (cm) | Area | | | Total |
|---|---|---|---|---|
| | 45-126 | 44-126 | North of Pt. Delgada | |
| 50 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | 1 | | 1 |
| 60 | | | | |
| 1 | | | | |
| 2 | 2 | | | 2 |
| 3 | 6 | 4 | 3 | 13 |
| 4 | 14 | 6 | 9 | 29 |
| 5 | 11 | 5 | 20 | 36 |
| 6 | 9 | 12 | 7 | 28 |
| 7 | 6 | 6 | 2 | 14 |
| 8 | 2 | 3 | 4 | 9 |
| 9 | | 1 | 1 | 2 |
| 70 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | 1 | | 1 |
| 4 | | 1 | | 1 |
| 5 | | 1 | 1 | 2 |
| 6 | | 2 | 1 | 3 |
| 7 | | 1 | | 1 |
| 8 | | 1 | | 1 |
| 9 | | 1 | 1 | 2 |
| 80 | | | 1 | 1 |
| 1 | | 2 | | 2 |
| 2 | | | | |
| 3 | | | | |
| 4 | | 1 | | 1 |
| 5 | | 1 | | 1 |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 90 | | | | |
| TOTAL | 50 | 50 | 50 | |
| Samples | 1 | 1 | 1 | |

Table 73
Albacore Length Frequencies
Astoria--July 1960

| Length (cm) | Area 45-125 | Area 36-125 | Total |
|---|---|---|---|
| 60 | | | |
| 1 | | | |
| 2 | 5 | | 5 |
| 3 | 7 | 3 | 10 |
| 4 | 20 | 6 | 26 |
| 5 | 24 | 9 | 33 |
| 6 | 19 | 7 | 26 |
| 7 | 13 | 2 | 15 |
| 8 | 5 | | 5 |
| 9 | 3 | | 3 |
| 70 | 5 | 1 | 6 |
| 1 | 6 | | 6 |
| 2 | 7 | 1 | 8 |
| 3 | 18 | 1 | 19 |
| 4 | 22 | 7 | 29 |
| 5 | 25 | 3 | 28 |
| 6 | 46 | 5 | 51 |
| 7 | 27 | | 27 |
| 8 | 28 | 2 | 30 |
| 9 | 27 | 1 | 28 |
| 80 | 7 | 2 | 9 |
| 1 | 5 | | 5 |
| 2 | 3 | | 3 |
| 3 | 1 | | 1 |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 90 | | | |
| TOTAL | 323 | 50 | |
| Samples | 7 | 1 | |

Table 74
Albacore Length Frequencies
Astoria--August 1960

| Length (cm) | Area | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | 45-125 | 45-126 | 46-125 | 47-125 | 45-124 | 44-126 | 38-124 | |
| 60 | | | | | | | | |
| 1 | | | | | | | | |
| 2 | 3 | | | | | | 1 | 4 |
| 3 | 7 | 1 | | 2 | 1 | | | 11 |
| 4 | 20 | | 2 | | 13 | 1 | 1 | 37 |
| 5 | 38 | 1 | 8 | 4 | 16 | 2 | 6 | 75 |
| 6 | 42 | | 4 | 5 | 33 | 2 | | 86 |
| 7 | 35 | 4 | 8 | 7 | 26 | 4 | 4 | 88 |
| 8 | 19 | | 9 | 9 | 16 | 3 | 2 | 58 |
| 9 | 21 | 2 | 5 | 5 | 9 | 2 | | 44 |
| 70 | 16 | | 4 | 2 | 4 | 1 | 1 | 28 |
| 1 | 11 | | 2 | 2 | 5 | | | 20 |
| 2 | 24 | 1 | 5 | | 3 | | | 33 |
| 3 | 39 | | 7 | 1 | 5 | 1 | 1 | 54 |
| 4 | 66 | 3 | 14 | 1 | 13 | 1 | 3 | 101 |
| 5 | 76 | 5 | 11 | 1 | 19 | 3 | 2 | 117 |
| 6 | 98 | 5 | 19 | 4 | 15 | 5 | 4 | 150 |
| 7 | 96 | 8 | 15 | 1 | 25 | 10 | 3 | 158 |
| 8 | 64 | 10 | 15 | 2 | 15 | 7 | 9 | 122 |
| 9 | 50 | 4 | 7 | 1 | 12 | 4 | 6 | 84 |
| 80 | 33 | 4 | 11 | 1 | 11 | 1 | 5 | 66 |
| 1 | 28 | 1 | 2 | 1 | 7 | 1 | | 40 |
| 2 | 8 | 1 | 2 | 1 | 2 | 2 | | 16 |
| 3 | 3 | | | | | | 2 | 5 |
| 4 | | | | | | | | |
| 5 | 2 | | | | | | | 2 |
| 6 | 1 | | | | | | | 1 |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 90 | | | | | | | | |
| TOTAL | 800 | 50 | 150 | 50 | 250 | 50 | 50 | |
| Samples | 12 | 1 | 3 | 1 | 5 | 1 | 1 | |

Table 75
Albacore Length Frequencies
Astoria--September 1960

| Length (cm) | Area | | | | | Total |
|---|---|---|---|---|---|---|
| | 45-125 | 46-125 | 45-124 | 40-125 | 39-125 | |
| 60 | | | | | | |
| 1 | | | | | | |
| 2 | | | | 5 | | 5 |
| 3 | 1 | | | 14 | 1 | 16 |
| 4 | | | 1 | 20 | 1 | 22 |
| 5 | 3 | 4 | 3 | 50 | 5 | 65 |
| 6 | 9 | 7 | 10 | 68 | 11 | 105 |
| 7 | 15 | 8 | 6 | 63 | 5 | 97 |
| 8 | 11 | 7 | 19 | 27 | 5 | 69 |
| 9 | 11 | 2 | 4 | 17 | 6 | 40 |
| 70 | 8 | 2 | | 6 | | 16 |
| 1 | 3 | 2 | | 3 | 2 | 10 |
| 2 | 2 | 1 | 1 | 5 | | 9 |
| 3 | | | 2 | 3 | 1 | 6 |
| 4 | 1 | 1 | | 1 | 3 | 6 |
| 5 | 2 | 2 | | 1 | 2 | 7 |
| 6 | 4 | 3 | 1 | 4 | 2 | 14 |
| 7 | 9 | 2 | 1 | 2 | 1 | 15 |
| 8 | 7 | 4 | 1 | 2 | 1 | 15 |
| 9 | 3 | 3 | 1 | 3 | | 10 |
| 80 | 6 | 2 | | 2 | 1 | 11 |
| 1 | 2 | | | 1 | 1 | 4 |
| 2 | 2 | | | 2 | 1 | 5 |
| 3 | 1 | | | 1 | | 2 |
| 4 | | | | | 1 | 1 |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 90 | | | | | | |
| TOTAL | 100 | 50 | 50 | 300 | 50 | |
| Samples | 2 | 1 | 1 | 6 | 1 | |

Table 76
Albacore Length Frequencies
Astoria--October 1960

| Length (cm) | Area 38-125 |
|---|---|
| 60 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | 4 |
| 5 | 9 |
| 6 | 10 |
| 7 | 12 |
| 8 | 7 |
| 9 | 3 |
| 70 | 2 |
| 1 | |
| 2 | 1 |
| 3 | |
| 4 | |
| 5 | 1 |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 80 | 1 |
| TOTAL | 50 |
| Samples | 1 |

Table 77
Albacore Length Frequencies
Newport--August 1960

| Length (cm) | Area 45-124 |
|---|---|
| 60 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | 1 |
| 7 | |
| 8 | 4 |
| 9 | |
| 70 | |
| 1 | 1 |
| 2 | 1 |
| 3 | 2 |
| 4 | 1 |
| 5 | 1 |
| 6 | 2 |
| 7 | 9 |
| 8 | 5 |
| 9 | 1 |
| 80 | 10 |
| 1 | 2 |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | 1 |
| 90 | |
| TOTAL | 41 |
| Samples | 1 |

Table 78
Albacore Length Frequencies
Coos Bay--September 1960

| Length (cm) | Area Unknown |
|---|---|
| 60 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | 4 |
| 5 | 7 |
| 6 | 14 |
| 7 | 17 |
| 8 | 10 |
| 9 | 8 |
| 70 | 2 |
| 1 | 3 |
| 2 | 1 |
| 3 | 1 |
| 4 | 2 |
| 5 | 5 |
| 6 | 8 |
| 7 | 6 |
| 8 | 3 |
| 9 | 1 |
| 80 | 6 |
| 1 | |
| 2 | 1 |
| 3 | 1 |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 90 | |
| TOTAL | 100 |
| Samples | 2 |

Table 79
Albacore Length-Frequency Distributions
in Per Cent by Month and Year

| Length (cm) | 1939 | | | 1940 | | | | 1941 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Aug. | Sept. | Oct. | July | Aug. | Sept. | Oct. | July | Aug. | Sept. |
| 49 | | | | 0.0 | | | | 0.0 | | |
| 50 | | | | 0.1 | | | | 0.3 | 0.0 | |
| 1 | | | | 0.1 | | | | 0.6 | 0.3 | |
| 2 | | | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.3 | 1.1 | |
| 3 | | | 0.2 | 0.4 | 0.1 | 0.4 | 0.7 | 0.9 | 1.8 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 1.2 | 0.0 | 0.6 | 1.4 | 0.0 |
| 5 | 0.1 | 0.1 | 0.0 | 0.6 | 0.2 | 0.0 | 0.0 | 0.4 | 2.1 | 0.6 |
| 6 | 0.0 | 0.0 | 0.2 | 1.1 | 0.3 | 0.4 | 1.4 | 1.5 | 1.7 | 0.6 |
| 7 | 0.3 | 0.0 | 0.4 | 2.9 | 0.5 | 0.0 | 0.7 | 1.7 | 1.7 | 0.6 |
| 8 | 0.6 | 0.1 | 0.2 | 3.0 | 0.9 | 0.8 | 1.4 | 1.3 | 2.0 | 0.0 |
| 9 | 0.6 | 0.2 | 0.4 | 4.9 | 1.1 | 0.4 | 0.7 | 1.9 | 2.4 | 0.0 |
| 60 | 0.8 | 0.4 | 0.8 | 5.7 | 2.4 | 1.2 | 0.7 | 1.6 | 1.8 | 0.6 |
| 1 | 1.6 | 0.7 | 0.2 | 4.6 | 1.8 | 1.2 | 0.7 | 1.3 | 1.8 | 0.0 |
| 2 | 5.0 | 1.8 | 1.8 | 8.9 | 2.0 | 0.8 | 0.0 | 2.9 | 2.3 | 1.2 |
| 3 | 3.2 | 2.3 | 1.6 | 8.0 | 3.9 | 1.2 | 2.1 | 8.3 | 4.0 | 1.2 |
| 4 | 6.2 | 2.7 | 4.1 | 9.4 | 3.8 | 2.3 | 0.7 | 10.1 | 8.3 | 3.1 |
| 5 | 1.4 | 1.6 | 2.0 | 3.9 | 4.7 | 1.6 | 0.0 | 12.8 | 10.5 | 2.5 |
| 6 | 1.5 | 1.8 | 4.5 | 4.6 | 4.3 | 3.5 | 2.1 | 13.1 | 10.8 | 6.2 |
| 7 | 0.8 | 0.8 | 1.4 | 3.0 | 2.8 | 2.0 | 3.4 | 8.6 | 10.5 | 6.2 |
| 8 | 0.6 | 0.6 | 0.8 | 1.4 | 3.8 | 2.3 | 1.4 | 5.7 | 6.5 | 8.1 |
| 9 | 2.7 | 1.8 | 0.6 | 3.6 | 4.3 | 2.7 | 0.7 | 3.1 | 4.8 | 2.5 |
| 70 | 1.9 | 1.7 | 0.8 | 2.7 | 4.1 | 1.6 | 2.8 | 1.7 | 3.6 | 8.1 |
| 1 | 9.8 | 9.1 | 3.9 | 4.2 | 4.7 | 3.5 | 2.1 | 2.2 | 1.8 | 4.3 |
| 2 | 7.8 | 6.1 | 2.9 | 4.0 | 8.2 | 1.6 | 0.7 | 1.9 | 1.8 | 2.5 |
| 3 | 15.5 | 16.5 | 7.4 | 7.3 | 7.4 | 6.3 | 4.1 | 2.0 | 3.2 | 2.5 |
| 4 | 14.0 | 17.2 | 14.6 | 5.7 | 10.7 | 5.1 | 2.8 | 2.2 | 1.7 | 3.7 |
| 5 | 6.0 | 7.9 | 8.4 | 3.5 | 8.0 | 6.6 | 6.9 | 1.7 | 1.6 | 3.7 |
| 6 | 9.9 | 14.1 | 16.4 | 2.8 | 5.9 | 10.5 | 8.3 | 2.5 | 2.4 | 2.5 |
| 7 | 3.3 | 3.7 | 5.9 | 1.4 | 4.8 | 9.4 | 9.0 | 1.3 | 2.1 | 5.6 |
| 8 | 3.9 | 5.6 | 10.5 | 0.8 | 2.7 | 9.4 | 9.0 | 2.3 | 1.7 | 3.7 |
| 9 | 0.6 | 1.1 | 2.7 | 0.4 | 1.8 | 7.4 | 9.7 | 1.2 | 0.8 | 2.5 |
| 80 | 0.9 | 1.3 | 2.7 | 0.2 | 1.0 | 5.9 | 6.9 | 0.9 | 1.2 | 5.0 |
| 1 | 0.4 | 0.6 | 2.0 | 0.0 | 1.1 | 3.5 | 4.1 | 1.0 | 0.7 | 4.3 |
| 2 | 0.3 | 0.1 | 0.4 | 0.1 | 0.5 | 2.3 | 3.4 | 0.4 | 0.3 | 3.7 |
| 3 | 0.4 | 0.1 | 1.0 | 0.2 | 0.5 | 1.6 | 2.8 | 0.7 | 0.2 | 7.5 |
| 4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.5 | 0.8 | 2.1 | 0.1 | 0.3 | 2.5 |
| 5 | | 0.2 | 0.4 | 0.1 | 0.5 | 0.4 | 2.8 | 0.3 | 0.4 | 0.0 |
| 6 | | 0.0 | 0.6 | 0.1 | 0.4 | 0.4 | 2.8 | 0.3 | 0.2 | 1.9 |
| 7 | | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 2.1 | 0.1 | 0.0 | 1.9 |
| 8 | | 0.1 | | 0.0 | 0.1 | 1.2 | 0.0 | 0.0 | | 0.6 |
| 9 | | 0.0 | | | 0.0 | 0.4 | 0.7 | | | 0.0 |
| 90 | | 0.0 | | | | 0.4 | 0.7 | | | |
| 1 | | 0.1 | | | | 0.0 | 0.0 | | | |
| 2 | | 0.0 | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| No. of Fish Sampled: | 1,168 | 1,590 | 572 | 1,620 | 1,102 | 256 | 145 | 686 | 1,043 | 161 |

Table 79 (Continued)

| Length (cm) | 1942 | | | 1947 | | | | 1948 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | July | Aug. | Sept. | Oct. | July | Aug. | Sept. |
| 49 | 0.0 | 0.0 | | 0.0 | | | | | 0.0 | 0.0 |
| 50 | 0.1 | 0.1 | | 0.1 | | 0.0 | | 0.0 | 0.2 | 0.8 |
| 1 | 0.0 | T | | 0.1 | | 0.1 | | 0.2 | 0.0 | 0.6 |
| 2 | 0.9 | 0.1 | | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 1.7 |
| 3 | 0.3 | 0.3 | | 0.1 | 0.3 | 0.4 | 0.3 | 0.1 | 0.0 | 1.5 |
| 4 | 0.6 | 0.2 | | 0.1 | 0.5 | 0.8 | 0.0 | 0.2 | 0.2 | 1.5 |
| 5 | 1.6 | 0.3 | | 0.5 | 0.3 | 0.4 | 0.7 | 0.7 | 0.7 | 1.5 |
| 6 | 1.2 | 0.6 | | 0.6 | 0.5 | 0.3 | 2.0 | 1.6 | 1.4 | 2.9 |
| 7 | 1.6 | 1.5 | 0.0 | 1.5 | 0.5 | 0.7 | 1.3 | 2.1 | 2.0 | 2.5 |
| 8 | 4.3 | 2.2 | 0.3 | 2.2 | 1.2 | 0.6 | 0.7 | 3.8 | 3.4 | 5.1 |
| 9 | 6.8 | 3.5 | 0.6 | 3.3 | 1.7 | 1.6 | 2.5 | 5.5 | 4.2 | 5.8 |
| 60 | 6.2 | 5.9 | 1.9 | 5.4 | 2.5 | 2.1 | 2.2 | 9.2 | 8.6 | 8.3 |
| 1 | 10.6 | 7.5 | 3.8 | 7.4 | 3.8 | 2.8 | 4.5 | 14.1 | 8.6 | 9.5 |
| 2 | 14.1 | 11.4 | 6.4 | 13.6 | 6.1 | 3.1 | 5.0 | 16.0 | 12.5 | 11.8 |
| 3 | 13.5 | 14.2 | 8.9 | 14.9 | 12.8 | 6.5 | 6.0 | 13.6 | 12.3 | 10.0 |
| 4 | 8.9 | 14.3 | 15.5 | 14.4 | 14.8 | 8.9 | 7.9 | 11.3 | 10.3 | 10.7 |
| 5 | 9.0 | 10.4 | 18.0 | 13.2 | 14.7 | 12.9 | 12.7 | 3.8 | 5.0 | 5.7 |
| 6 | 3.7 | 7.2 | 15.8 | 7.6 | 12.0 | 14.8 | 9.8 | 1.9 | 4.1 | 3.8 |
| 7 | 2.3 | 3.9 | 9.7 | 5.7 | 8.0 | 13.5 | 13.8 | 1.3 | 2.3 | 2.8 |
| 8 | 1.3 | 1.5 | 5.4 | 2.9 | 4.9 | 11.1 | 11.4 | 1.1 | 2.5 | 1.9 |
| 9 | 0.9 | 0.8 | 3.4 | 1.4 | 2.8 | 7.8 | 8.3 | 1.9 | 3.9 | 2.4 |
| 70 | 0.8 | 0.7 | 1.5 | 0.9 | 2.1 | 3.9 | 3.8 | 1.1 | 2.0 | 0.6 |
| 1 | 0.7 | 0.6 | 0.6 | 0.1 | 1.3 | 1.6 | 2.2 | 1.2 | 1.0 | 1.3 |
| 2 | 0.6 | 0.6 | 0.4 | 0.5 | 1.2 | 1.9 | 1.9 | 1.0 | 1.4 | 0.5 |
| 3 | 1.0 | 1.2 | 0.7 | 0.3 | 0.6 | 0.8 | 1.2 | 1.8 | 1.7 | 0.8 |
| 4 | 0.9 | 1.2 | 1.2 | 0.4 | 1.0 | 1.0 | 0.4 | 1.7 | 1.8 | 1.3 |
| 5 | 0.7 | 1.6 | 0.9 | 0.2 | 0.8 | 0.4 | 0.0 | 1.1 | 1.5 | 1.0 |
| 6 | 1.2 | 1.6 | 1.0 | 0.1 | 0.5 | 0.3 | 0.3 | 1.3 | 2.3 | 0.9 |
| 7 | 1.3 | 1.3 | 0.6 | 0.4 | 1.0 | 0.1 | 0.0 | 1.2 | 1.4 | 0.8 |
| 8 | 0.8 | 1.3 | 0.9 | 0.2 | 1.2 | 0.3 | 0.0 | 0.3 | 1.6 | 1.0 |
| 9 | 1.0 | 0.9 | 0.6 | 0.1 | 0.5 | 0.5 | 0.1 | 0.2 | 0.9 | 0.5 |
| 80 | 0.5 | 1.2 | 0.6 | 0.1 | 0.5 | 0.1 | 0.1 | 0.4 | 0.6 | 0.1 |
| 1 | 0.3 | 0.7 | 0.7 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.6 | 0.0 |
| 2 | 1.0 | 0.5 | 0.3 | 0.2 | 0.3 | 0.1 | 0.1 | 0.0 | 0.2 | 0.0 |
| 3 | 0.6 | 0.2 | 0.1 | 0.5 | 0.3 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 |
| 4 | 0.2 | 0.3 | 0.0 | 0.1 | 0.3 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 |
| 5 | 0.1 | 0.1 | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 |
| 6 | 0.3 | 0.1 | 0.0 | 0.2 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 |
| 7 | 0.0 | 0.1 | | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | | 0.0 |
| 8 | 0.0 | 0.1 | | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | | |
| 9 | 0.0 | 0.0 | | 0.0 | 0.1 | 0.1 | | 0.0 | | |
| 90 | 0.1 | T | | 0.1 | 0.1 | 0.0 | | | | |
| 1 | 0.0 | 0.0 | | 0.0 | 0.0 | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| No. of Fish Sampled: | 867 | 3,580 | 683 | 991 | 1,541 | 1,463 | 683 | 1,230 | 813 | 787 |

Table 79 (Continued)

| Length (cm) | 1949 | | | 1950 | | | | 1951 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | July | Aug. | Sept. | Oct. | July | Aug. | Sept. | Oct. |
| 44 | | | 0.0 | | | | | | | | |
| 5 | | | 0.1 | | | | | | | | |
| 6 | | | 0.0 | | | | | | | | |
| 7 | | | 0.0 | | | | | | | | |
| 8 | | | 0.0 | | | | | | | | |
| 9 | | | 0.0 | | | | | 0.0 | | | |
| 50 | | | 0.2 | | | | | 0.3 | | | |
| 1 | | | 1.2 | | | | 0.0 | 0.0 | 0.0 | | |
| 2 | | | 2.8 | | 0.0 | 0.0 | 1.4 | 0.0 | 0.4 | 0.0 | |
| 3 | | | 2.3 | | 0.1 | 0.4 | 0.5 | 0.0 | 0.4 | 0.5 | |
| 4 | | | 3.0 | | 0.1 | 0.8 | 0.0 | 0.3 | 0.8 | 0.3 | |
| 5 | 0.0 | | 0.8 | | 0.1 | 0.8 | 1.0 | 0.9 | 0.6 | 0.9 | 0.0 |
| 6 | 0.4 | 0.0 | 0.9 | 0.0 | 0.3 | 0.6 | 1.4 | 1.6 | 2.0 | 0.7 | 1.0 |
| 7 | 1.6 | 0.3 | 1.2 | 0.1 | 1.2 | 0.6 | 1.9 | 3.5 | 4.4 | 2.3 | 0.0 |
| 8 | 2.1 | 0.6 | 2.1 | 0.3 | 1.3 | 2.8 | 2.9 | 2.5 | 5.0 | 2.6 | 1.0 |
| 9 | 3.0 | 2.5 | 5.4 | 0.9 | 3.1 | 3.8 | 2.4 | 6.3 | 7.6 | 5.9 | 2.0 |
| 60 | 5.8 | 5.4 | 10.3 | 1.7 | 7.5 | 7.6 | 5.3 | 6.0 | 7.0 | 6.3 | 2.0 |
| 1 | 5.4 | 8.3 | 17.0 | 1.1 | 10.8 | 12.0 | 6.7 | 11.7 | 11.0 | 6.1 | 8.0 |
| 2 | 5.1 | 7.5 | 22.2 | 2.2 | 10.8 | 12.0 | 14.4 | 8.2 | 10.6 | 7.9 | 13.0 |
| 3 | 4.4 | 7.0 | 12.9 | 1.7 | 7.0 | 7.6 | 16.7 | 8.5 | 6.2 | 11.3 | 19.0 |
| 4 | 4.8 | 5.9 | 7.2 | 1.3 | 5.6 | 6.4 | 12.9 | 9.1 | 7.6 | 12.0 | 19.0 |
| 5 | 4.4 | 6.2 | 2.4 | 1.7 | 3.2 | 3.2 | 9.1 | 6.9 | 6.0 | 8.7 | 14.0 |
| 6 | 5.0 | 5.6 | 1.1 | 1.5 | 1.8 | 1.6 | 2.4 | 3.5 | 2.4 | 4.5 | 4.0 |
| 7 | 8.4 | 7.4 | 1.0 | 3.2 | 3.1 | 1.8 | 0.5 | 3.5 | 3.2 | 4.9 | 3.0 |
| 8 | 10.5 | 6.9 | 1.2 | 4.8 | 3.5 | 2.0 | 1.4 | 1.6 | 2.2 | 2.6 | 3.0 |
| 9 | 9.3 | 7.6 | 0.7 | 9.4 | 5.7 | 5.0 | 1.0 | 1.3 | 1.4 | 1.0 | 2.0 |
| 70 | 6.9 | 8.4 | 1.0 | 13.8 | 7.2 | 4.2 | 2.4 | 1.3 | 2.2 | 2.8 | 3.0 |
| 1 | 5.4 | 6.0 | 0.8 | 14.6 | 8.5 | 6.8 | 2.4 | 2.2 | 3.0 | 3.1 | 2.0 |
| 2 | 5.8 | 4.6 | 0.5 | 11.3 | 6.6 | 6.4 | 1.4 | 2.2 | 2.0 | 1.9 | 0.0 |
| 3 | 3.1 | 2.3 | 0.2 | 10.6 | 5.2 | 5.0 | 1.9 | 0.3 | 2.6 | 3.1 | 1.0 |
| 4 | 1.6 | 2.3 | 0.5 | 6.3 | 3.0 | 3.0 | 1.4 | 0.3 | 1.8 | 1.0 | 0.0 |
| 5 | 1.4 | 1.6 | 0.2 | 4.3 | 1.7 | 1.8 | 1.9 | 0.0 | 1.0 | 2.1 | 0.0 |
| 6 | 1.5 | 0.7 | 0.3 | 2.4 | 0.9 | 0.6 | 1.4 | 0.6 | 0.2 | 1.7 | 2.0 |
| 7 | 0.5 | 0.3 | 0.1 | 1.6 | 0.4 | 1.6 | 1.4 | 2.5 | 0.8 | 1.0 | 0.0 |
| 8 | 1.1 | 0.4 | 0.0 | 1.1 | 0.4 | 1.2 | 0.5 | 0.6 | 1.2 | 0.3 | 0.0 |
| 9 | 0.8 | 0.5 | 0.2 | 1.6 | 0.1 | 0.4 | 1.4 | 1.6 | 0.8 | 0.0 | 0.0 |
| 80 | 0.6 | 0.4 | 0.0 | 0.8 | 0.1 | 0.4 | 1.4 | 1.6 | 0.8 | 0.9 | 0.0 |
| 1 | 0.4 | 0.4 | 0.1 | 0.7 | 0.3 | 0.0 | 0.0 | 1.6 | 0.8 | 0.0 | 0.0 |
| 2 | 0.1 | 0.4 | 0.0 | 0.6 | 0.0 | | 0.5 | 2.5 | 0.8 | 0.9 | 0.0 |
| 3 | 0.3 | 0.2 | 0.0 | 0.2 | 0.0 | | 0.0 | 3.2 | 0.6 | 0.3 | 0.0 |
| 4 | 0.4 | 0.2 | 0.1 | 0.1 | 0.0 | | | 0.9 | 1.0 | 0.9 | 0.0 |
| 5 | 0.1 | 0.2 | 0.1 | 0.0 | 0.1 | | | 1.3 | 0.6 | 0.7 | 1.0 |
| 6 | 0.0 | 0.1 | 0.0 | 0.4 | 0.0 | | | 0.6 | 0.6 | 0.3 | 0.0 |
| 7 | 0.0 | 0.0 | 0.0 | 0.0 | | | | 0.6 | 0.2 | 0.0 | |
| 8 | 0.1 | | 0.2 | | | | | 0.0 | 0.0 | | |
| 9 | 0.0 | | 0.0 | | | | | 0.3 | 0.2 | | |
| 90 | | | | | | | | 0.0 | 0.0 | | |
| No. of Fish Sampled: | 800 | 1,133 | 1,302 | 1,512 | 926 | 502 | 209 | 317 | 500 | 573 | 100 |

Table 79 (Continued)

| Length (cm) | 1952 | | | | 1953 | | | | 1954 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | Aug. | Sept. | Oct. 1/ | Oct. 2/ | Sept. | Oct. |
| 49 | | | | | | 0.0 | | | | 0.0 |
| 50 | | | 0.0 | | | 0.3 | | 0.0 | 0.0 | 0.9 |
| 1 | | 0.0 | 0.1 | | | 0.5 | | 2.0 | 4.4 | 0.0 |
| 2 | | 0.1 | 0.7 | | 0.0 | 3.5 | | 4.0 | 11.4 | 2.8 |
| 3 | | 0.1 | 1.3 | | 3.0 | 5.0 | | 17.0 | 11.0 | 4.7 |
| 4 | | 0.3 | 1.1 | 0.0 | 4.0 | 8.3 | | 23.0 | 11.0 | 3.8 |
| 5 | 0.0 | 0.1 | 0.7 | 0.6 | 2.0 | 12.0 | | 16.0 | 6.6 | 4.7 |
| 6 | 0.3 | 0.9 | 1.0 | 0.8 | 3.0 | 7.3 | | 18.0 | 2.9 | 3.8 |
| 7 | 0.3 | 0.4 | 1.6 | 1.1 | 5.0 | 6.3 | | 5.0 | 3.3 | 2.8 |
| 8 | 0.3 | 1.4 | 2.1 | 0.8 | 0.0 | 4.0 | 0.0 | 3.0 | 3.3 | 3.8 |
| 9 | 0.0 | 2.0 | 3.4 | 1.1 | 0.0 | 1.3 | 1.6 | 1.0 | 2.2 | 1.9 |
| 60 | 0.6 | 4.1 | 4.5 | 1.9 | 2.0 | 1.5 | 3.2 | 2.0 | 0.7 | 0.9 |
| 1 | 2.6 | 7.3 | 8.2 | 4.1 | 2.0 | 2.0 | 0.0 | 0.0 | 2.9 | 0.9 |
| 2 | 1.6 | 9.7 | 10.0 | 4.1 | 3.0 | 2.0 | 0.0 | 0.0 | 0.7 | 1.9 |
| 3 | 5.8 | 11.5 | 11.1 | 9.1 | 3.0 | 5.3 | 0.0 | 0.0 | 1.8 | 1.9 |
| 4 | 5.4 | 10.1 | 10.5 | 6.9 | 18.0 | 10.5 | 0.0 | 1.0 | 3.3 | 5.7 |
| 5 | 7.0 | 10.9 | 9.5 | 8.6 | 22.0 | 5.8 | 3.2 | 3.0 | 5.1 | 7.5 |
| 6 | 4.2 | 7.8 | 7.3 | 9.9 | 10.0 | 8.8 | 4.8 | 1.0 | 7.0 | 15.1 |
| 7 | 6.1 | 7.7 | 4.4 | 6.9 | 9.0 | 5.0 | 6.5 | 1.0 | 5.9 | 10.4 |
| 8 | 6.1 | 3.7 | 3.4 | 6.4 | 2.0 | 4.3 | 6.5 | 2.0 | 5.5 | 11.3 |
| 9 | 5.4 | 4.2 | 2.3 | 4.4 | 2.0 | 1.5 | 3.2 | 1.0 | 3.3 | 5.7 |
| 70 | 7.7 | 3.4 | 2.2 | 3.3 | 0.0 | 0.5 | 3.2 | 0.0 | 4.4 | 4.7 |
| 1 | 7.0 | 4.1 | 2.6 | 3.6 | 1.0 | 0.8 | 4.8 | | 0.7 | 0.0 |
| 2 | 10.2 | 2.9 | 2.6 | 2.8 | 0.0 | 0.5 | 0.0 | | 0.0 | 0.0 |
| 3 | 6.4 | 1.9 | 2.3 | 3.9 | 0.0 | 0.5 | 3.2 | | 0.4 | 0.9 |
| 4 | 6.4 | 1.3 | 1.6 | 1.9 | 1.0 | 0.0 | 6.5 | | 0.0 | 0.0 |
| 5 | 5.1 | 1.4 | 1.3 | 2.2 | 0.0 | 0.0 | 0.0 | | 0.7 | 0.0 |
| 6 | 3.2 | 0.5 | 0.9 | 4.1 | 2.0 | 0.0 | 4.8 | | 0.0 | 0.0 |
| 7 | 2.2 | 0.8 | 0.8 | 2.5 | 2.0 | 0.0 | 0.0 | | 0.0 | 0.0 |
| 8 | 1.9 | 0.3 | 0.5 | 1.4 | 1.0 | 0.3 | 4.8 | | 0.0 | 0.9 |
| 9 | 1.6 | 0.3 | 0.5 | 0.8 | 0.0 | 0.3 | 6.5 | | 0.0 | 0.9 |
| 80 | 0.6 | 0.4 | 0.3 | 2.5 | 1.0 | 0.5 | 3.2 | | 0.0 | 0.0 |
| 1 | 0.3 | 0.0 | 0.1 | 1.1 | 0.0 | 0.3 | 3.2 | | 0.7 | 0.0 |
| 2 | 0.3 | 0.1 | 0.2 | 1.4 | 0.0 | 0.3 | 3.2 | | 0.0 | 0.0 |
| 3 | 1.0 | 0.0 | 0.0 | 0.3 | 2.0 | 0.5 | 8.1 | | 0.0 | 0.9 |
| 4 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 0.3 | 3.2 | | 0.0 | 0.9 |
| 5 | 0.0 | 0.1 | 0.1 | 0.3 | | 0.0 | 3.2 | | 0.0 | 0.0 |
| 6 | 0.0 | 0.0 | 0.1 | 0.0 | | 0.0 | 3.2 | | 0.0 | |
| 7 | 0.0 | | 0.2 | 0.3 | | 0.0 | 4.8 | | 0.4 | |
| 8 | 0.0 | | 0.1 | 0.0 | | 0.3 | 1.6 | | 0.0 | |
| 9 | 0.0 | | 0.1 | 0.3 | | 0.5 | 0.0 | | | |
| 90 | 0.0 | | T | 0.0 | | 0.0 | 0.0 | | | |
| 1 | 0.3 | | T | 0.0 | | | 1.6 | | | |
| 2 | 0.0 | | 0.0 | 0.0 | | | 0.0 | | | |
| 3 | | | | 0.0 | | | 0.0 | | | |
| 4 | | | | 0.0 | | | 0.0 | | | |
| 5 | | | | 0.3 | | | 0.0 | | | |
| 6 | | | | 0.0 | | | 0.0 | | | |
| 7 | | | | 0.0 | | | 1.6 | | | |
| 8 | | | | 0.0 | | | 0.0 | | | |
| 9 | | | | 0.0 | | | | | | |
| 100 | | | | 0.3 | | | | | | |
| 1 | | | | 0.0 | | | | | | |
| No. of Fish Sampled: | 313 | 790 | 2,047 | 362 | 100 | 400 | 62 | 100 | 272 | 106 |

1/ Astoria
2/ Newport

Table 79 (Continued)

| Length (cm) | 1955 | | 1956 | | 1957 | | | |
|---|---|---|---|---|---|---|---|---|
| | Sept. | Oct. | Aug. | Sept. | July | Aug. | Sept. | Oct. |
| 49 | | | | | | 0.0 | | |
| 50 | 0.0 | | | 0.0 | 0.0 | 0.1 | 0.0 | |
| 1 | 0.5 | | | 0.2 | 1.0 | 0.1 | T | |
| 2 | 1.0 | 0.0 | | 0.3 | 0.0 | 0.5 | 0.5 | |
| 3 | 1.3 | 2.8 | 0.0 | 0.7 | 0.0 | 1.5 | 1.4 | |
| 4 | 2.0 | 1.8 | 1.0 | 1.1 | 0.0 | 1.4 | 1.4 | |
| 5 | 0.3 | 1.8 | 1.0 | 1.8 | 0.0 | 1.4 | 1.0 | 0.0 |
| 6 | 1.0 | 1.3 | 2.5 | 0.8 | 0.0 | 0.8 | 1.1 | 0.3 |
| 7 | 0.5 | 0.8 | 1.5 | 1.2 | 0.0 | 0.7 | 0.6 | 0.0 |
| 8 | 1.8 | 2.3 | 0.5 | 0.9 | 1.0 | 0.6 | 1.0 | 0.3 |
| 9 | 6.5 | 1.3 | 0.0 | 0.3 | 1.0 | 1.3 | 1.1 | 0.6 |
| 60 | 9.3 | 5.3 | 0.5 | 0.5 | 0.0 | 1.3 | 1.8 | 2.1 |
| 1 | 17.5 | 12.3 | 1.0 | 0.9 | 3.0 | 2.3 | 2.2 | 4.2 |
| 2 | 22.8 | 21.3 | 0.0 | 4.3 | 8.0 | 4.2 | 4.0 | 5.1 |
| 3 | 15.5 | 19.3 | 2.5 | 6.4 | 8.0 | 9.1 | 6.8 | 5.4 |
| 4 | 8.8 | 13.3 | 4.5 | 11.5 | 24.0 | 13.4 | 11.6 | 10.6 |
| 5 | 4.5 | 8.8 | 14.0 | 15.2 | 26.0 | 15.9 | 18.5 | 15.1 |
| 6 | 2.8 | 3.8 | 16.5 | 17.9 | 18.0 | 11.9 | 18.3 | 21.1 |
| 7 | 0.0 | 1.8 | 12.0 | 15.8 | 6.0 | 6.1 | 11.7 | 14.2 |
| 8 | 0.5 | 0.8 | 6.5 | 8.1 | 0.0 | 2.2 | 4.3 | 7.9 |
| 9 | 0.8 | 0.3 | 5.5 | 4.9 | 1.0 | 1.1 | 2.5 | 6.6 |
| 70 | 1.3 | 0.3 | 4.0 | 2.0 | 0.0 | 0.4 | 0.5 | 1.5 |
| 1 | 0.3 | 0.0 | 1.5 | 0.7 | 0.0 | 0.5 | 0.4 | 0.3 |
| 2 | 0.0 | 0.0 | 2.0 | 0.9 | 1.0 | 0.8 | 0.4 | 0.3 |
| 3 | 0.0 | 0.0 | 4.0 | 0.6 | 1.0 | 1.2 | 0.3 | 0.0 |
| 4 | 0.0 | 0.0 | 5.0 | 0.5 | 1.0 | 2.7 | 0.5 | 0.3 |
| 5 | 0.3 | 0.0 | 5.5 | 0.4 | 0.0 | 2.9 | 1.0 | 0.0 |
| 6 | 0.0 | 0.0 | 4.0 | 1.0 | | 4.1 | 1.3 | 0.3 |
| 7 | 0.0 | 0.3 | 2.0 | 0.4 | | 3.8 | 1.3 | 0.6 |
| 8 | 0.8 | 0.3 | 2.0 | 0.3 | | 3.3 | 1.2 | 0.6 |
| 9 | 0.0 | 0.3 | 0.0 | 0.2 | | 1.7 | 1.3 | 0.9 |
| 80 | 0.5 | 0.3 | 0.5 | 0.1 | | 1.3 | 0.7 | 0.3 |
| 1 | 0.0 | 0.5 | 0.0 | 0.0 | | 0.8 | 0.8 | 0.6 |
| 2 | | 0.0 | | 0.0 | | 0.4 | 0.1 | 0.6 |
| 3 | | | | 0.0 | | 0.1 | 0.1 | 0.0 |
| 4 | | | | 0.0 | | T | T | |
| 5 | | | | 0.1 | | T | T | |
| 6 | | | | 0.0 | | 0.0 | 0.0 | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 90 | | | | | | | | |
| No. of Fish Sampled: | 400 | 400 | 200 | 1,000 | 100 | 3,428 | 2,032 | 331 |

Table 79 (Continued)

| Length (cm) | 1958 July | 1958 Aug. | 1958 Sept. | 1958 Oct. | 1959 July | 1959 Aug. | 1959 Sept. | 1960 July | 1960 Aug. | 1960 Sept. | 1960 Oct. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 0.0 | | | | | | | | | | |
| 50 | 0.2 | 0.0 | 0.0 | | | | | | | | |
| 1 | 0.0 | 0.1 | 0.1 | 0.0 | | | | | | | |
| 2 | 1.3 | 0.8 | 0.3 | 0.5 | | 0.0 | | | | | |
| 3 | 0.5 | 0.9 | 1.7 | 2.0 | | 0.1 | | | | | |
| 4 | 0.3 | 0.3 | 5.3 | 2.5 | | 0.1 | 0.0 | | | | |
| 5 | 0.5 | 0.3 | 8.3 | 4.0 | | 0.3 | 0.7 | | | | |
| 6 | 0.0 | 0.1 | 6.1 | 1.0 | | 0.2 | 1.0 | | | | |
| 7 | 0.0 | 0.1 | 2.9 | 2.0 | 0.0 | 0.0 | 0.7 | | | | |
| 8 | 0.2 | 0.1 | 1.2 | 1.0 | 0.2 | 0.1 | 1.3 | | | | |
| 9 | 0.8 | 0.7 | 0.3 | 0.0 | 0.1 | 0.6 | 1.0 | | | | |
| 60 | 1.7 | 1.3 | 0.3 | 0.0 | 0.1 | 0.1 | 0.7 | | | | |
| 1 | 2.5 | 1.5 | 0.3 | 0.5 | 0.3 | 0.7 | 3.3 | 0.0 | 0.0 | 0.0 | |
| 2 | 3.6 | 2.4 | 1.0 | 0.5 | 1.9 | 1.8 | 0.7 | 1.3 | 0.3 | 0.8 | |
| 3 | 5.6 | 5.9 | 2.3 | 0.5 | 7.4 | 4.8 | 4.0 | 2.7 | 0.8 | 2.5 | 0.0 |
| 4 | 8.3 | 7.3 | 4.0 | 2.5 | 15.6 | 11.9 | 7.7 | 7.0 | 2.6 | 4.0 | 8.0 |
| 5 | 16.0 | 10.5 | 6.2 | 4.5 | 23.0 | 19.7 | 11.7 | 8.8 | 5.2 | 11.2 | 18.0 |
| 6 | 17.7 | 12.5 | 7.5 | 8.0 | 19.0 | 24.3 | 16.0 | 7.0 | 6.0 | 18.3 | 20.0 |
| 7 | 15.5 | 13.5 | 11.3 | 9.0 | 12.1 | 17.0 | 17.7 | 4.0 | 6.1 | 17.5 | 24.0 |
| 8 | 10.4 | 9.8 | 9.2 | 13.0 | 7.3 | 8.6 | 11.0 | 1.3 | 4.3 | 12.2 | 14.0 |
| 9 | 6.4 | 7.7 | 10.6 | 10.0 | 2.6 | 3.9 | 9.0 | 0.8 | 3.1 | 7.4 | 6.0 |
| 70 | 4.6 | 5.6 | 5.6 | 11.0 | 0.6 | 1.6 | 2.7 | 1.6 | 1.9 | 2.8 | 4.0 |
| 1 | 1.8 | 2.7 | 4.8 | 6.0 | 0.6 | 0.5 | 1.7 | 1.6 | 1.5 | 2.0 | 0.0 |
| 2 | 0.5 | 0.9 | 2.6 | 4.0 | 0.1 | 0.1 | 0.7 | 2.1 | 2.4 | 1.5 | 2.0 |
| 3 | 0.3 | 0.9 | 1.2 | 0.5 | 0.6 | 0.1 | 0.3 | 5.1 | 3.9 | 1.1 | 0.0 |
| 4 | 0.0 | 0.3 | 0.1 | 1.5 | 0.3 | 0.1 | 0.3 | 7.8 | 7.1 | 1.2 | 0.0 |
| 5 | 0.2 | 0.2 | 0.0 | 0.5 | 0.8 | 0.3 | 0.0 | 7.5 | 8.2 | 1.8 | 2.0 |
| 6 | 0.0 | 0.9 | 0.3 | 0.5 | 0.4 | 0.2 | 0.0 | 13.7 | 10.5 | 3.4 | 0.0 |
| 7 | 0.5 | 1.2 | 0.3 | 0.5 | 1.3 | 0.5 | 0.0 | 7.2 | 11.6 | 3.2 | 0.0 |
| 8 | 0.2 | 1.9 | 0.1 | 3.5 | 0.9 | 0.5 | 0.3 | 8.0 | 8.8 | 2.8 | 0.0 |
| 9 | 0.2 | 2.3 | 0.6 | 1.0 | 1.7 | 0.5 | 1.0 | 7.5 | 5.9 | 1.7 | 0.0 |
| 80 | 0.2 | 2.1 | 1.0 | 1.5 | 0.8 | 0.5 | 1.3 | 2.4 | 5.3 | 2.6 | 2.0 |
| 1 | 0.2 | 1.3 | 1.2 | 1.0 | 0.8 | 0.4 | 0.7 | 1.3 | 2.6 | 0.6 | 0.0 |
| 2 | 0.0 | 2.0 | 0.9 | 2.0 | 0.6 | 0.4 | 1.3 | 0.8 | 1.1 | 0.9 | |
| 3 | | 0.9 | 0.6 | 2.0 | 0.2 | 0.3 | 1.3 | 0.3 | 0.3 | 0.5 | |
| 4 | | 0.6 | 0.9 | 2.0 | 0.3 | 0.1 | 0.7 | 0.0 | 0.0 | 0.2 | |
| 5 | | 0.3 | 0.5 | 0.5 | 0.3 | 0.0 | 0.7 | | 0.1 | 0.0 | |
| 6 | | 0.0 | 0.1 | 0.0 | 0.0 | | 0.3 | | 0.1 | | |
| 7 | | | 0.1 | 0.0 | | | 0.0 | | 0.0 | | |
| 8 | | | 0.0 | 0.0 | | | | | 0.0 | | |
| 9 | | | | 0.0 | | | | | 0.1 | | |
| 90 | | | | 0.5 | | | | | 0.0 | | |
| 1 | | | | 0.0 | | | | | | | |
| No. of Fish Sampled: | 606 | 905 | 771 | 200 | 900 | 1,050 | 300 | 373 | 1,441 | 650 | 50 |

Figure 1
Catch Localities for Pacific Albacore
July 1951

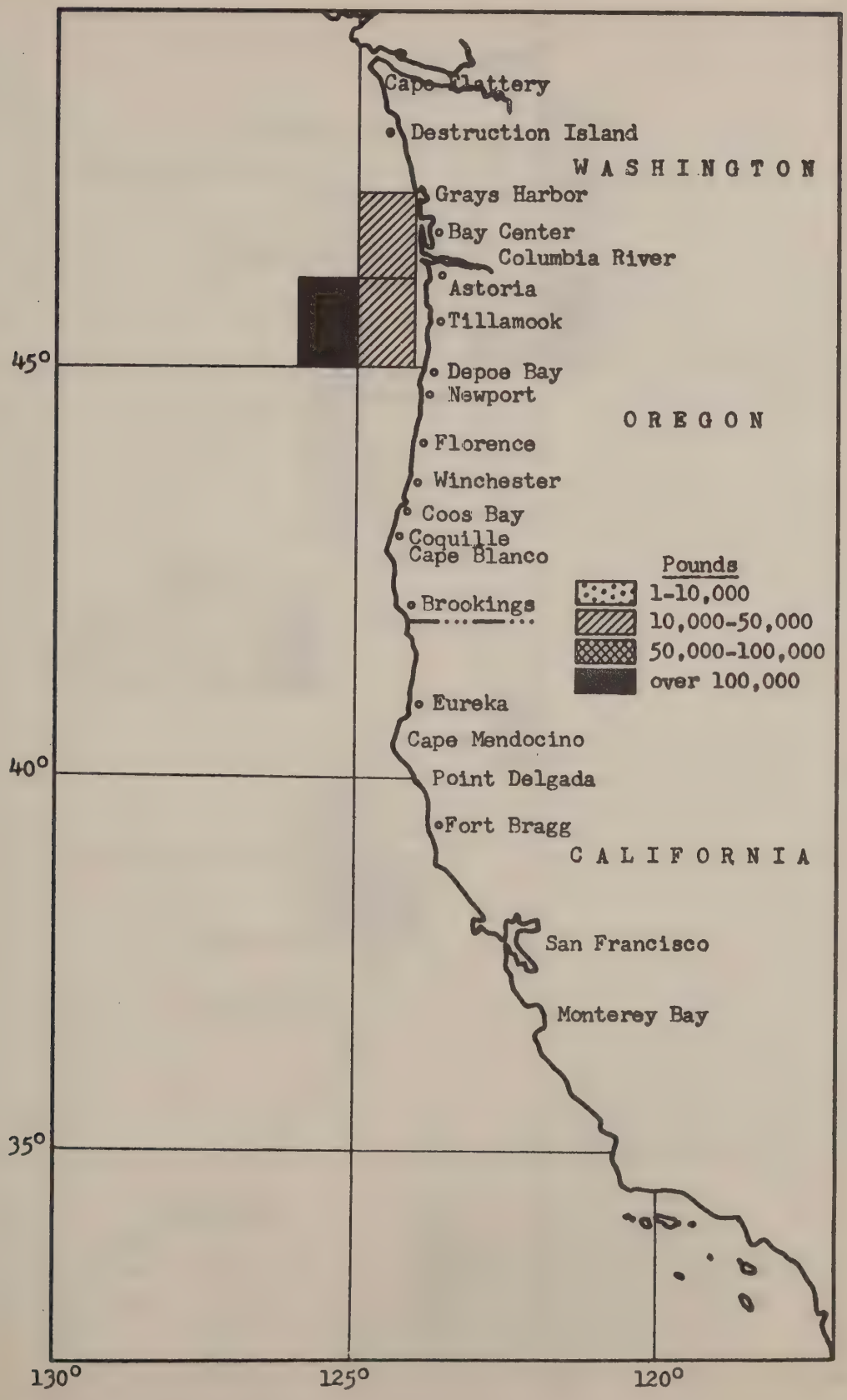


Figure 2
Catch Localities for Pacific Albacore
August 1951

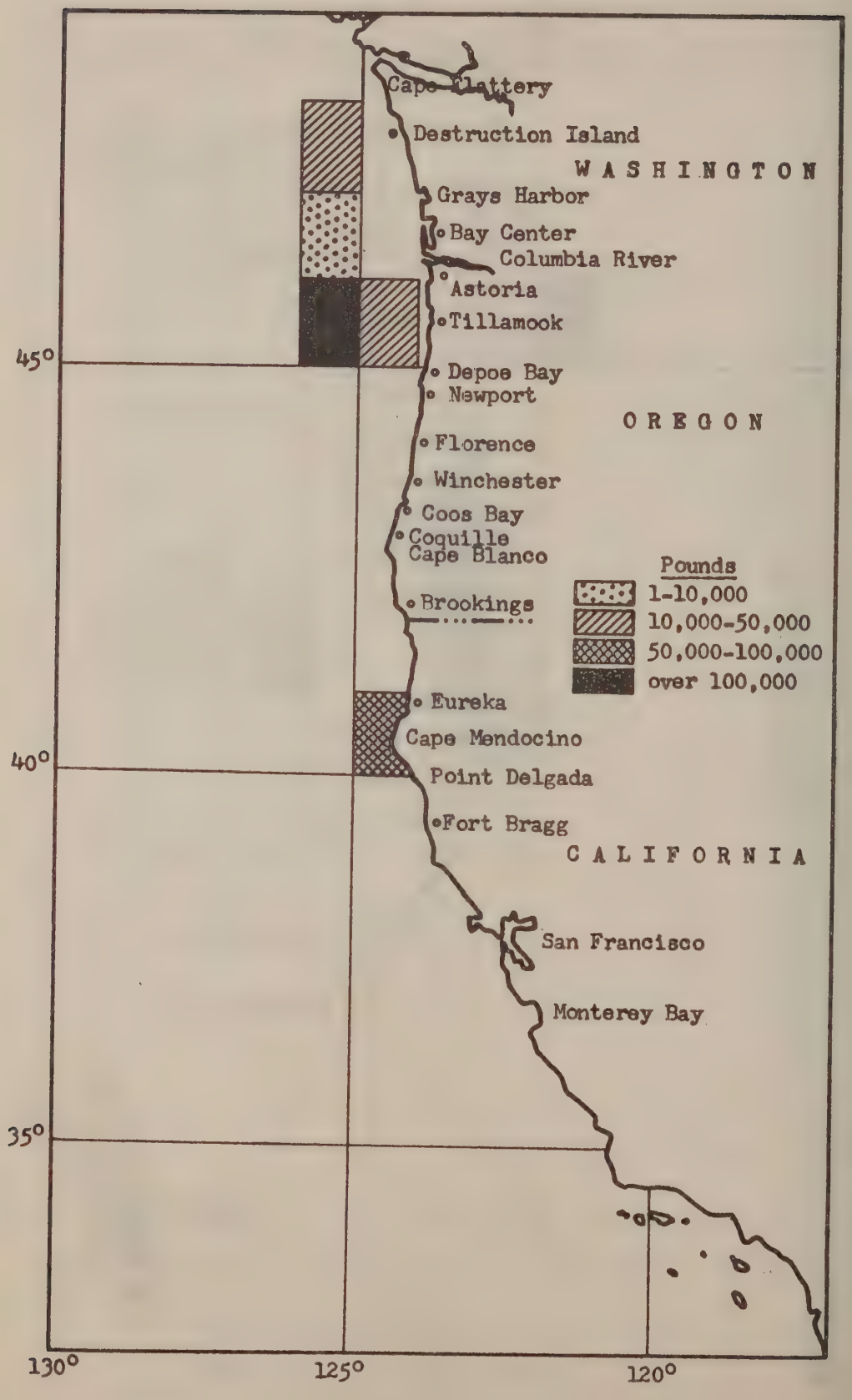


Figure 3
Catch Localities for Pacific Albacore
September 1951

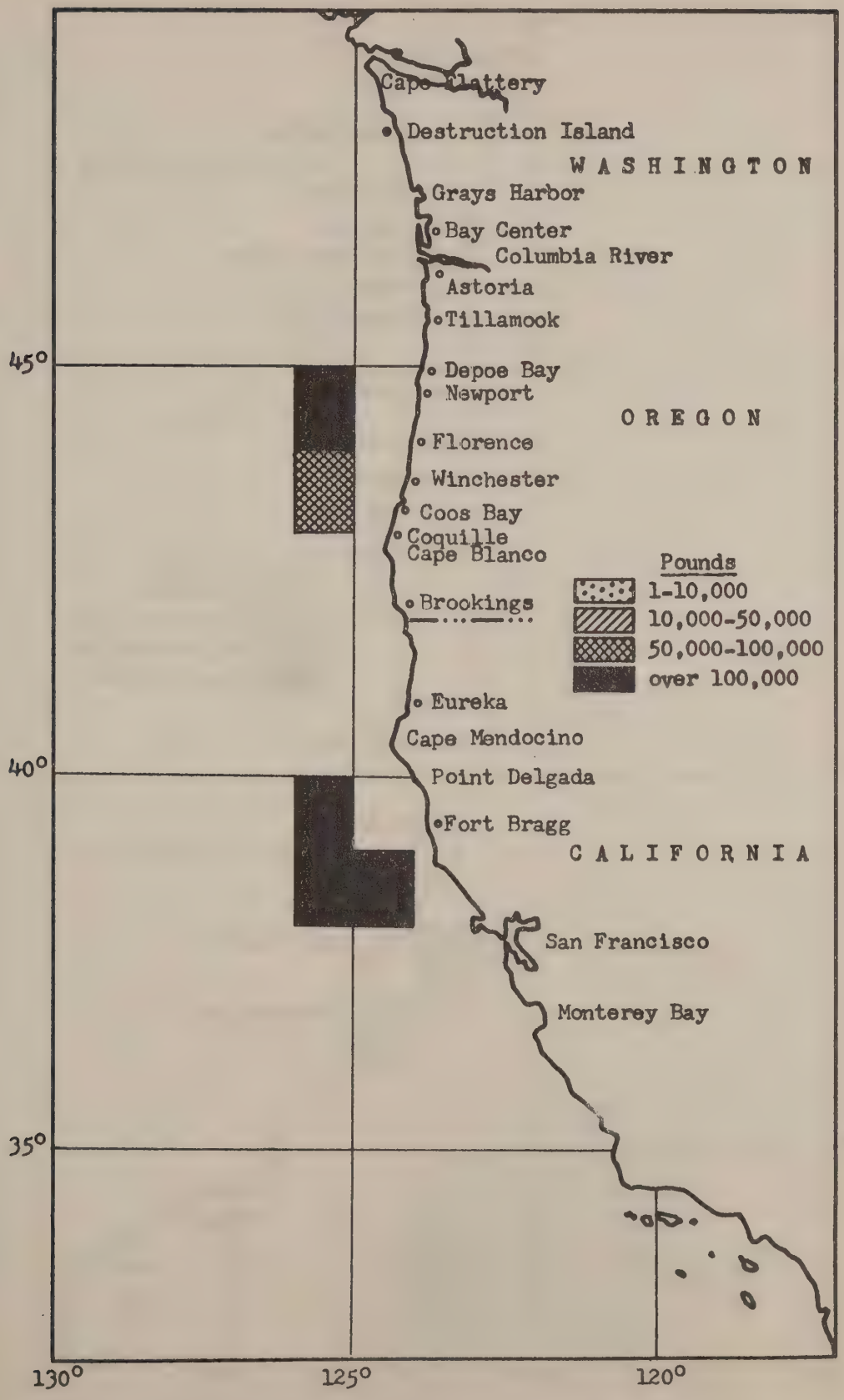


Figure 4
Catch Localities for Pacific Albacore
November 1951

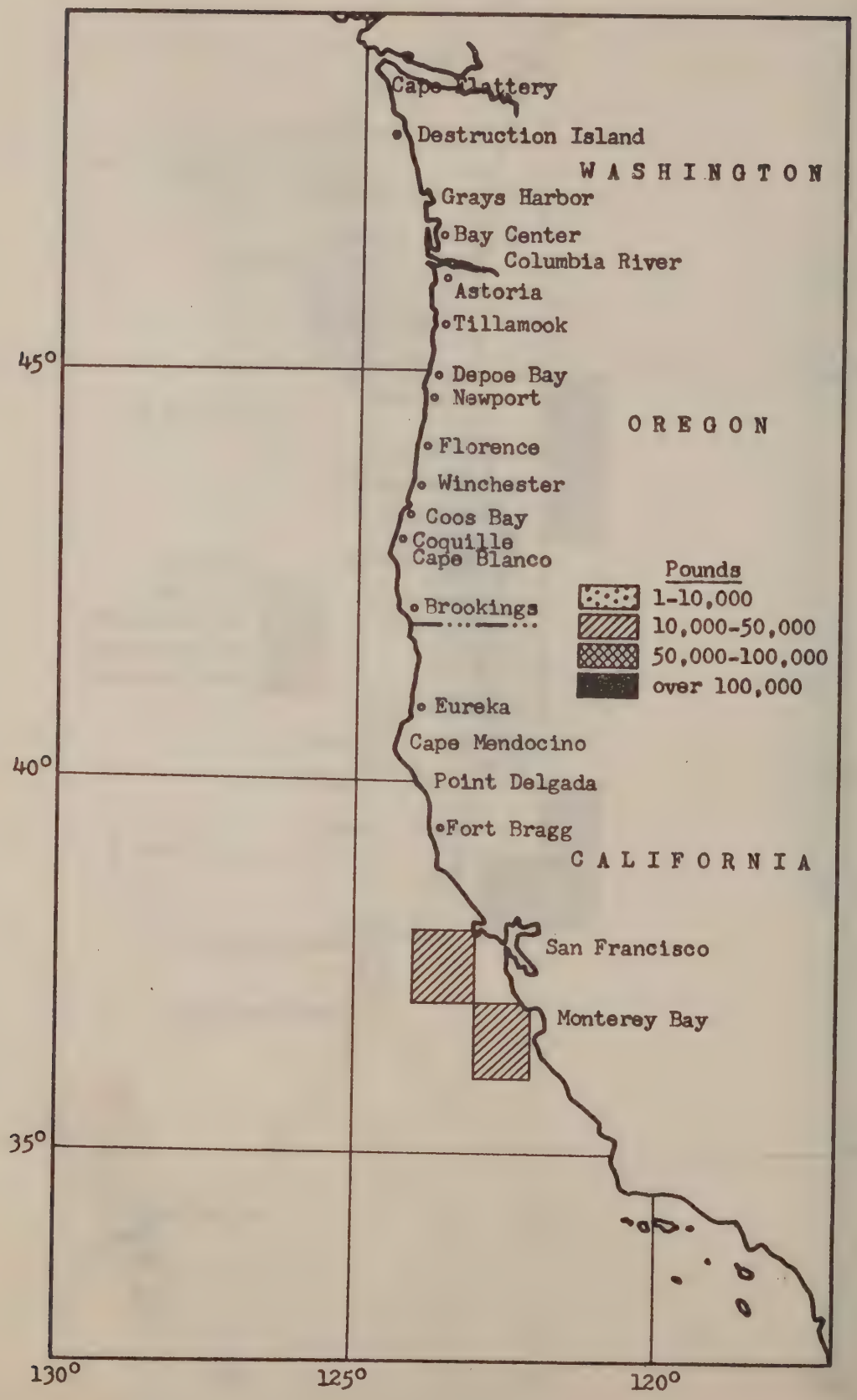


Figure 5
Catch Localities for Pacific Albacore
July 1952

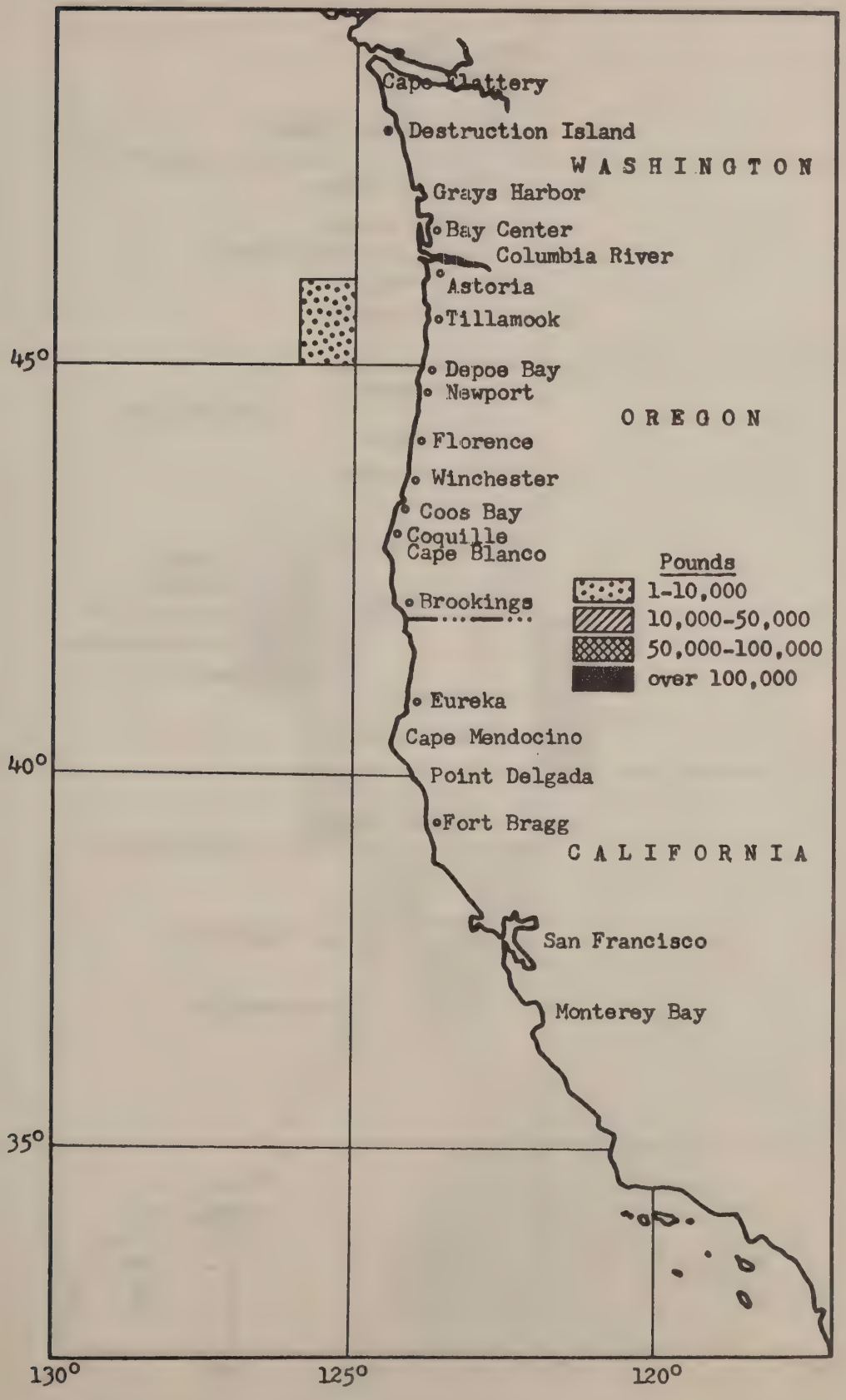


Figure 6
Catch Localities for Pacific Albacore
August 1952

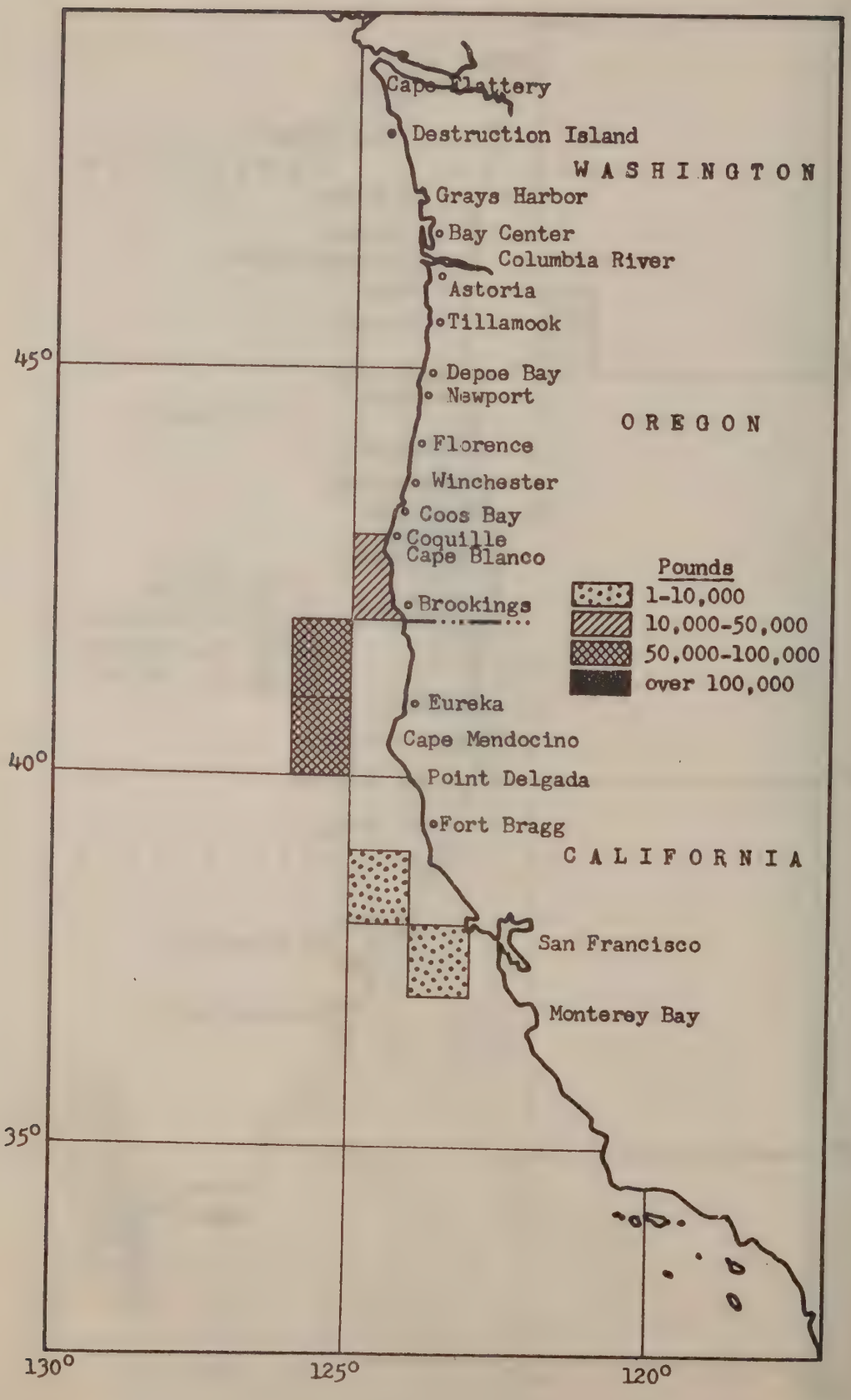


Figure 7
Catch Localities for Pacific Albacore
September 1952

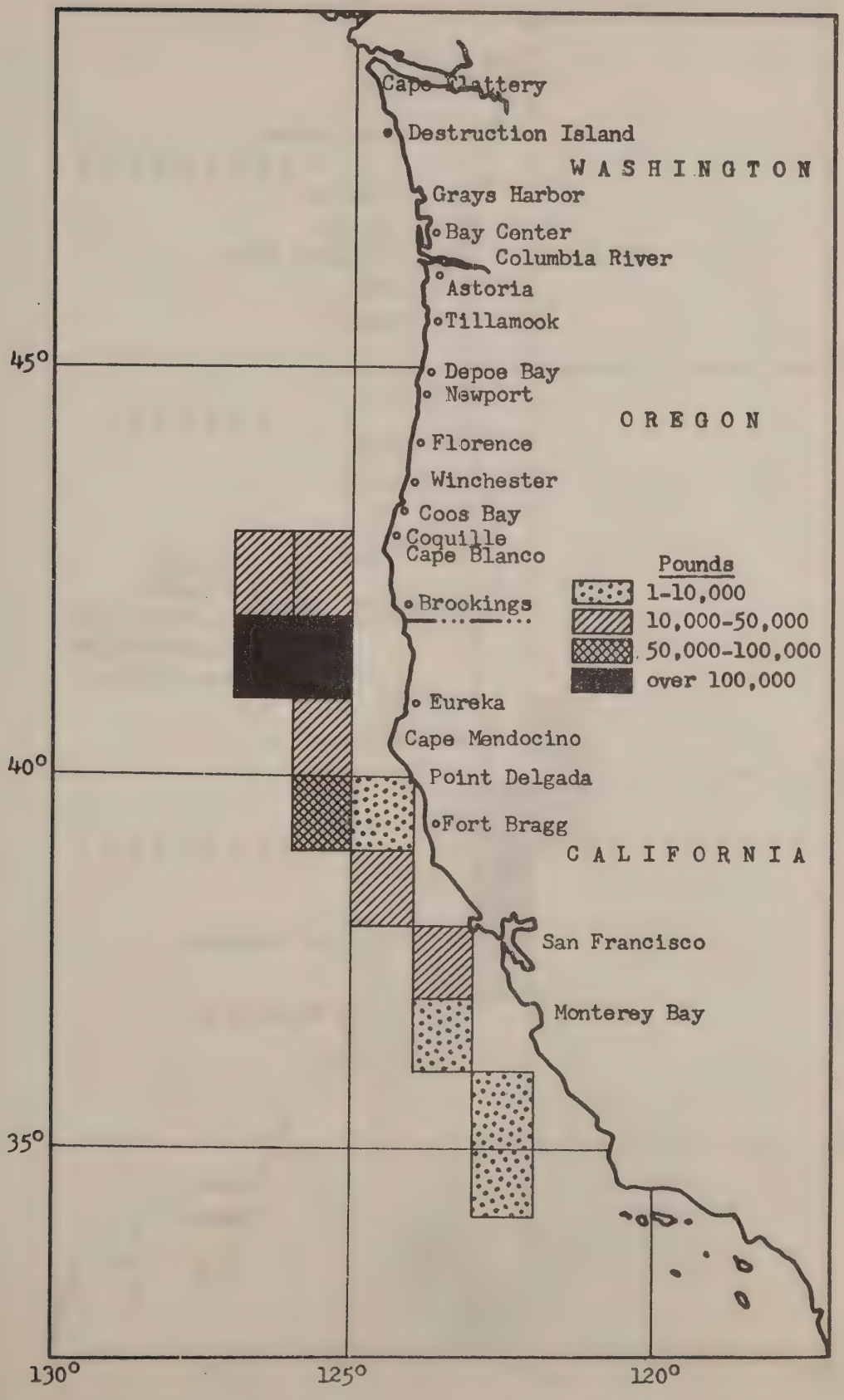


Figure 8
Catch Localities for Pacific Albacore
October 1952

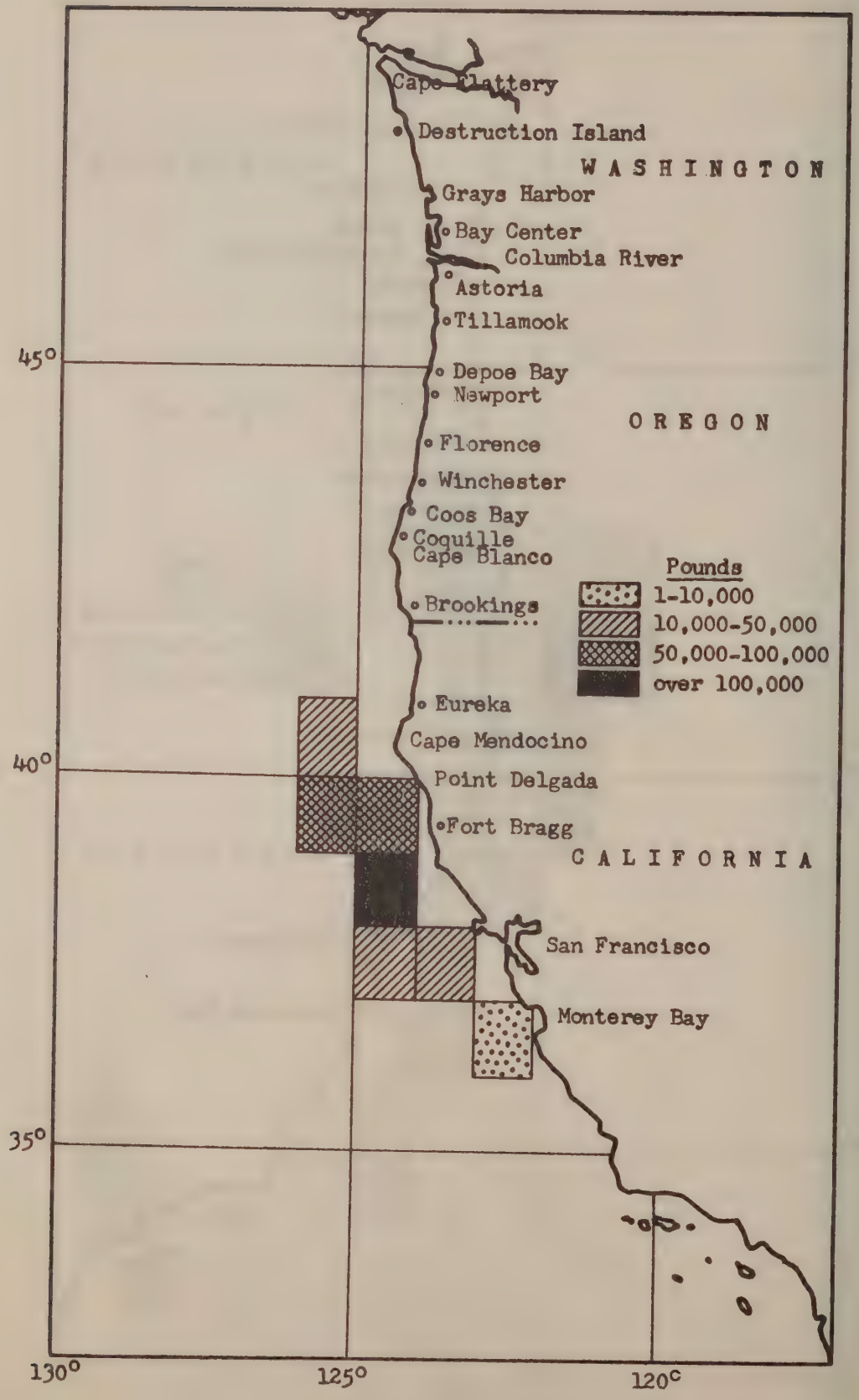


Figure 9
Catch Localities for Pacific Albacore
August 1953

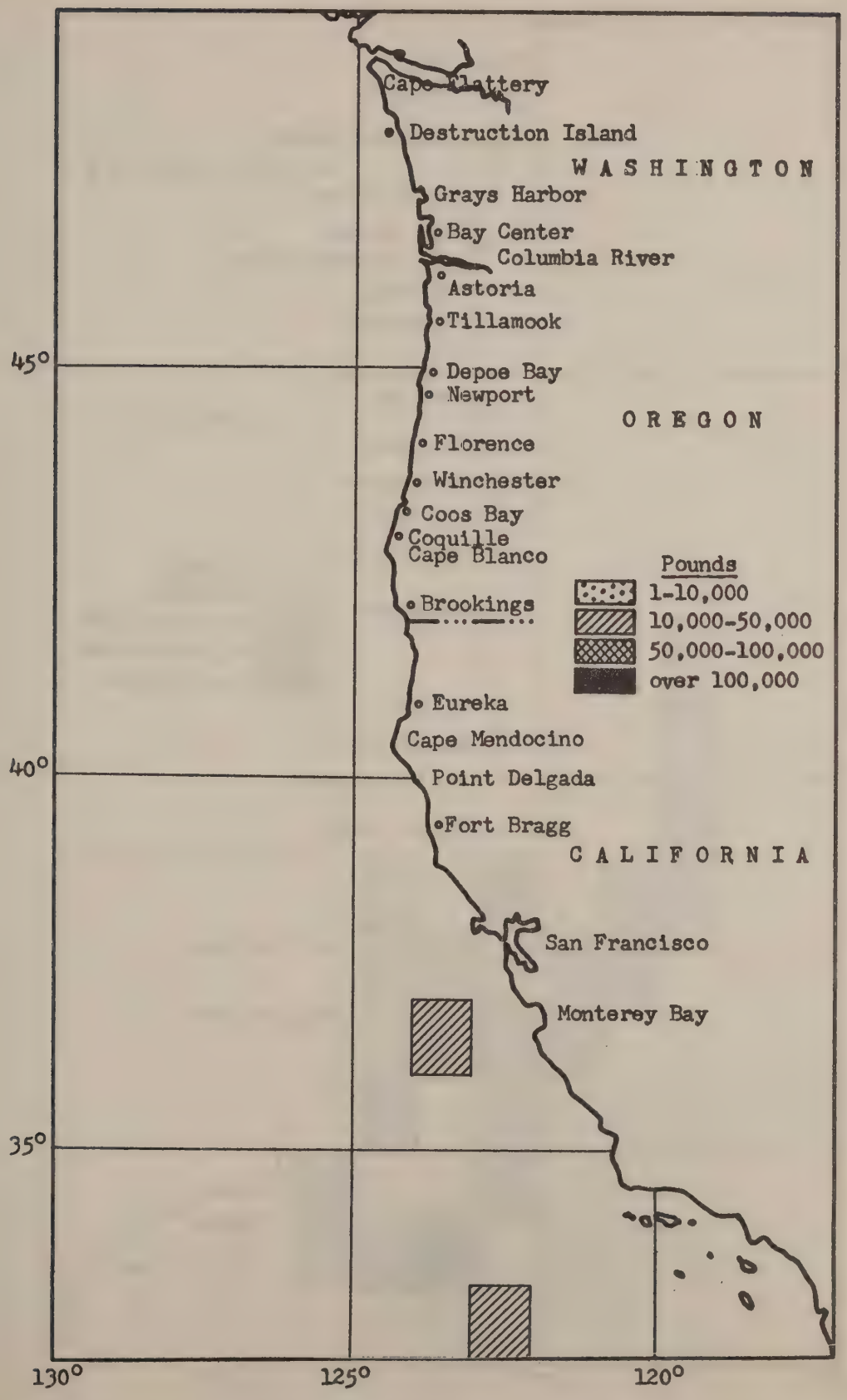


Figure 10
Catch Localities for Pacific Albacore
September 1953

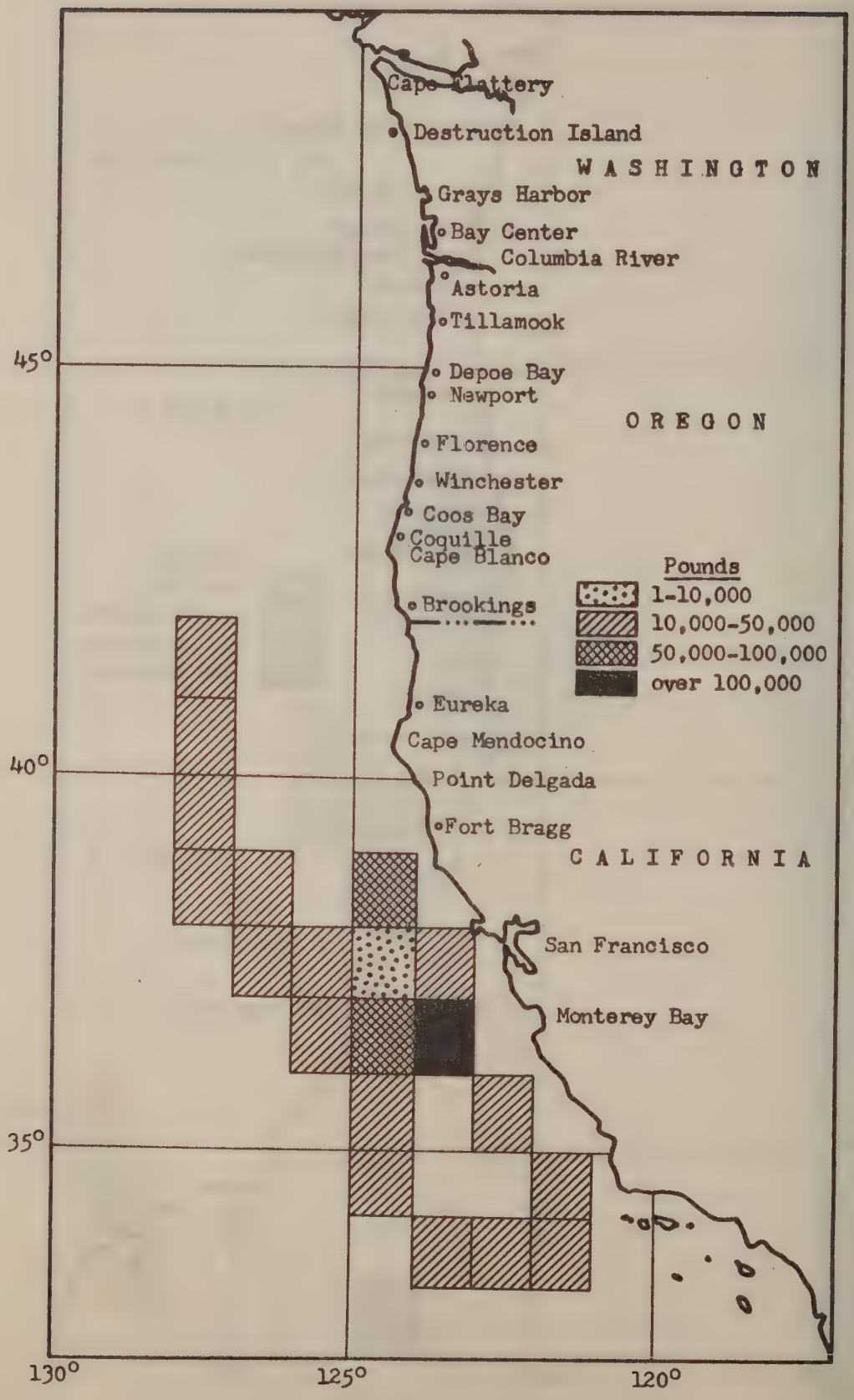


Figure 11
Catch Localities for Pacific Albacore
October 1953

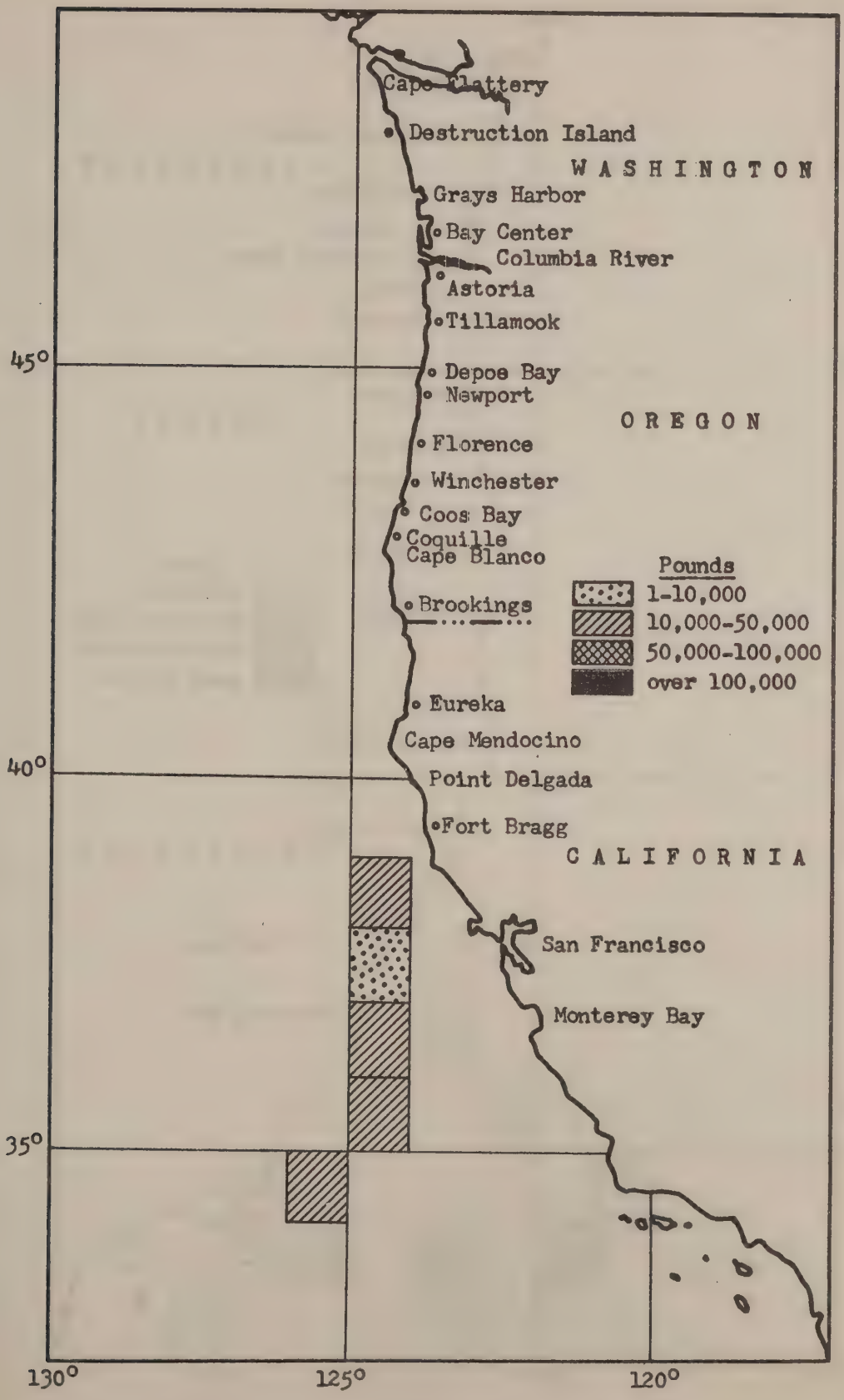


Figure 12
Catch Localities for Pacific Albacore
August 1954

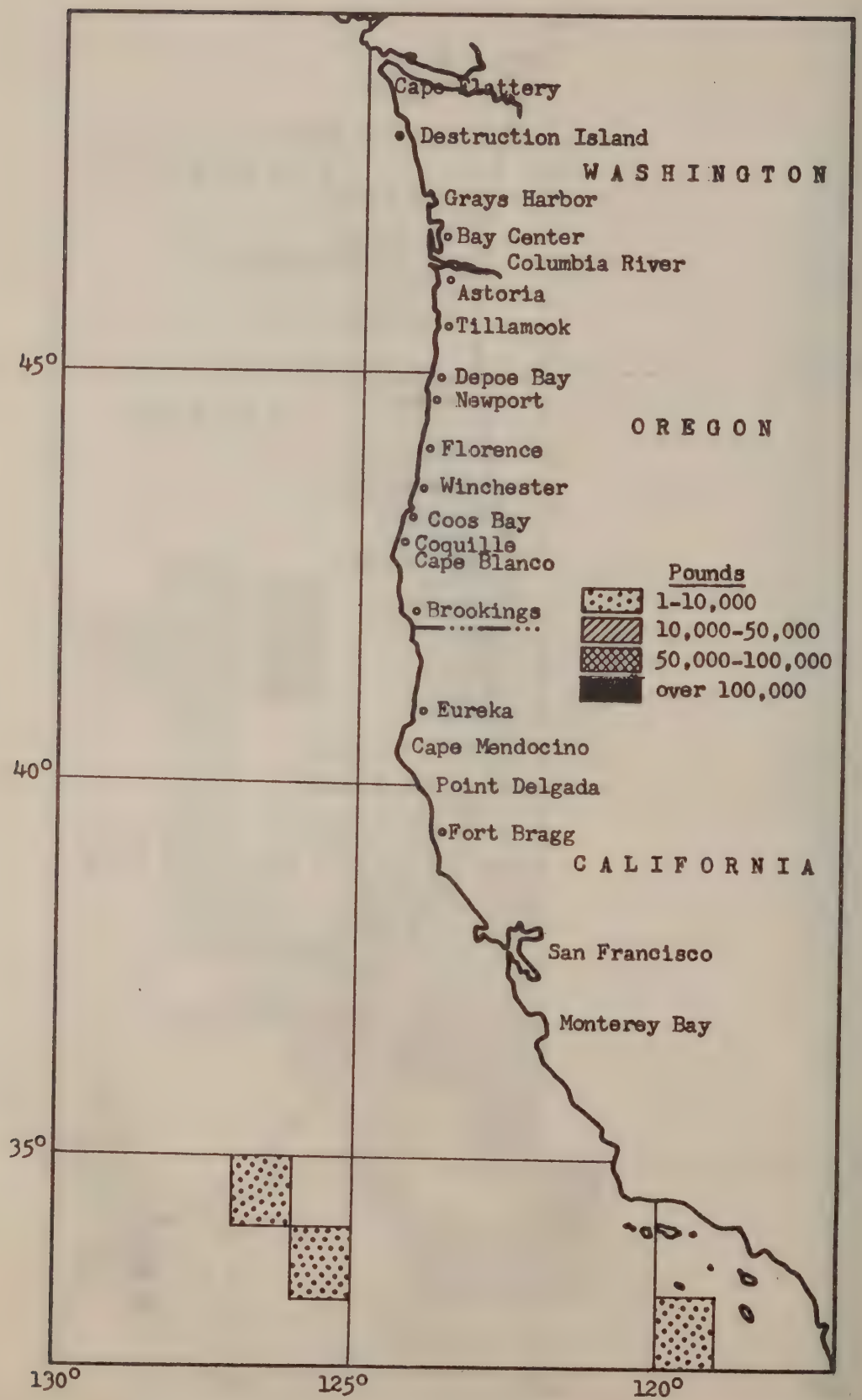


Figure 13
Catch Localities for Pacific Albacore
September 1954

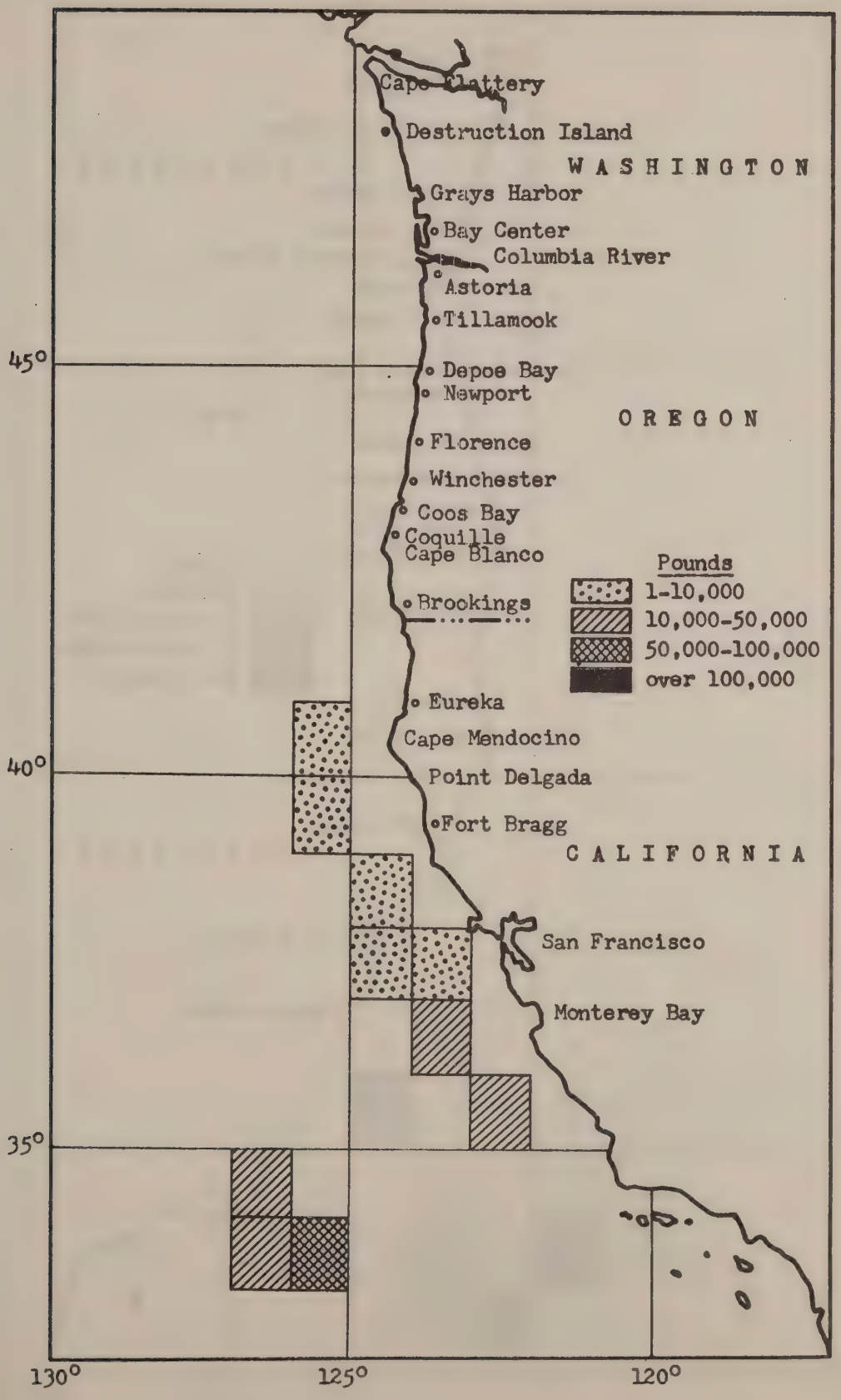


Figure 14
Catch Localities for Pacific Albacore
October 1954

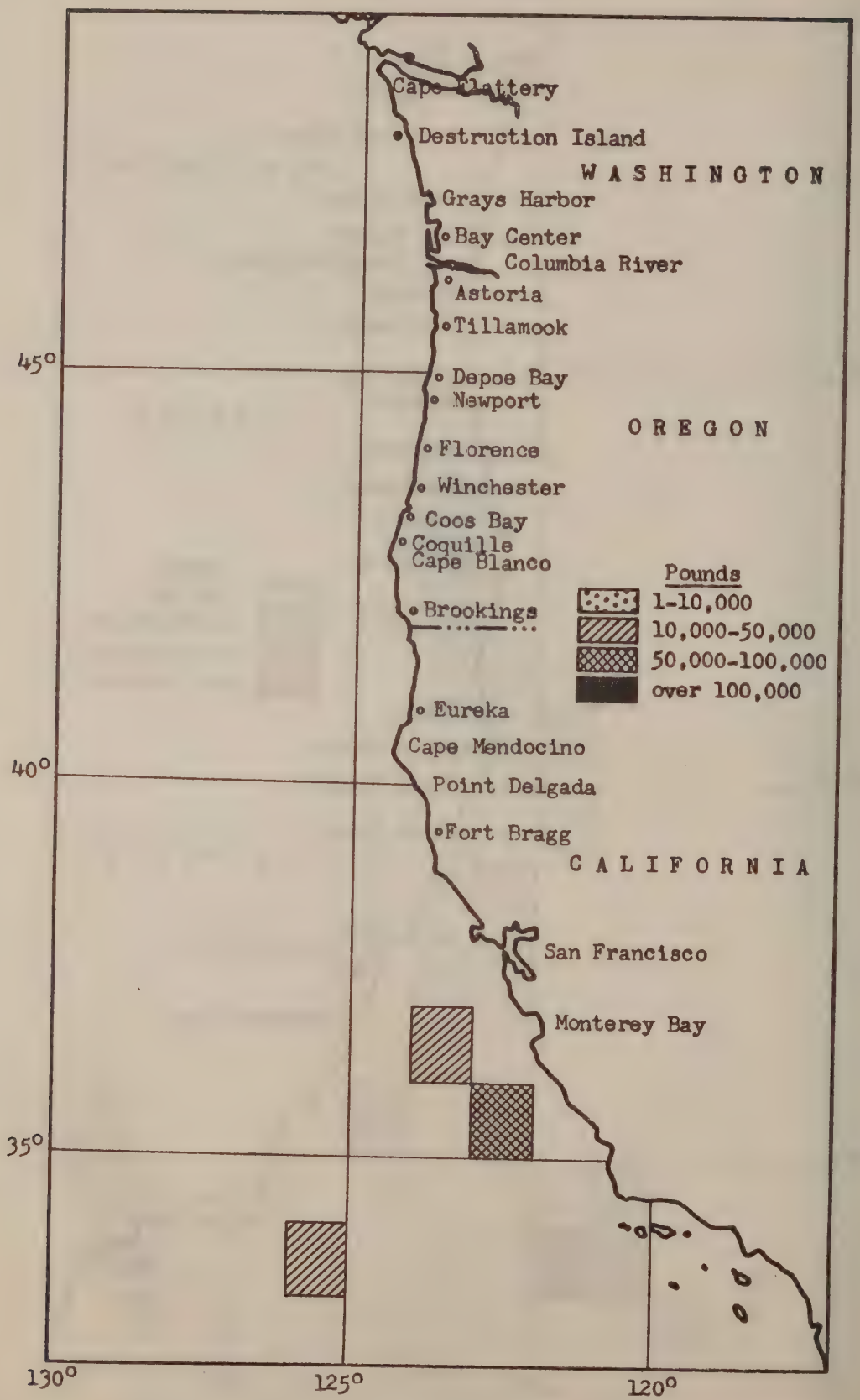


Figure 15
Catch Localities for Pacific Albacore
September 1955

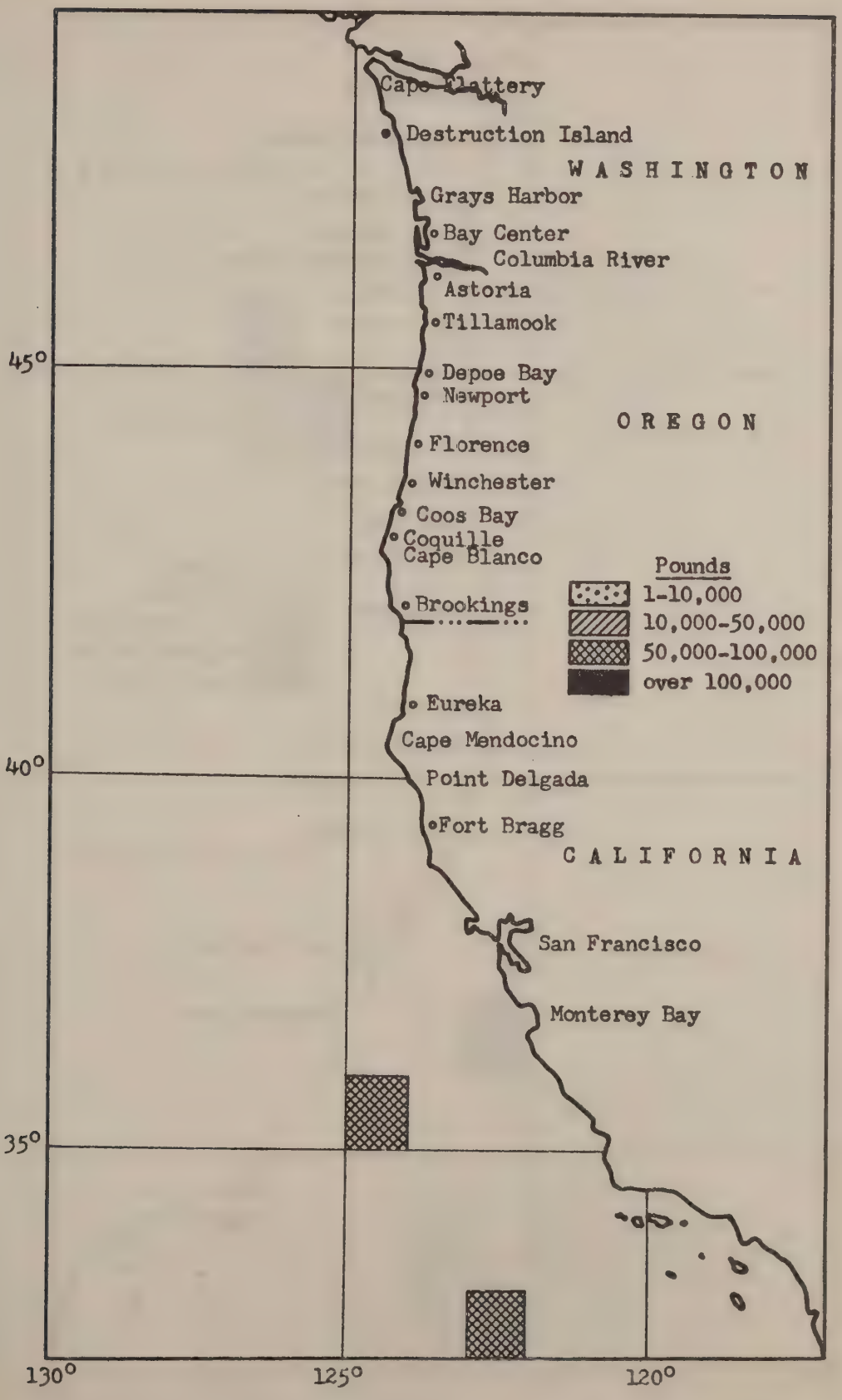


Figure 16
Catch Localities for Pacific Albacore
October 1955

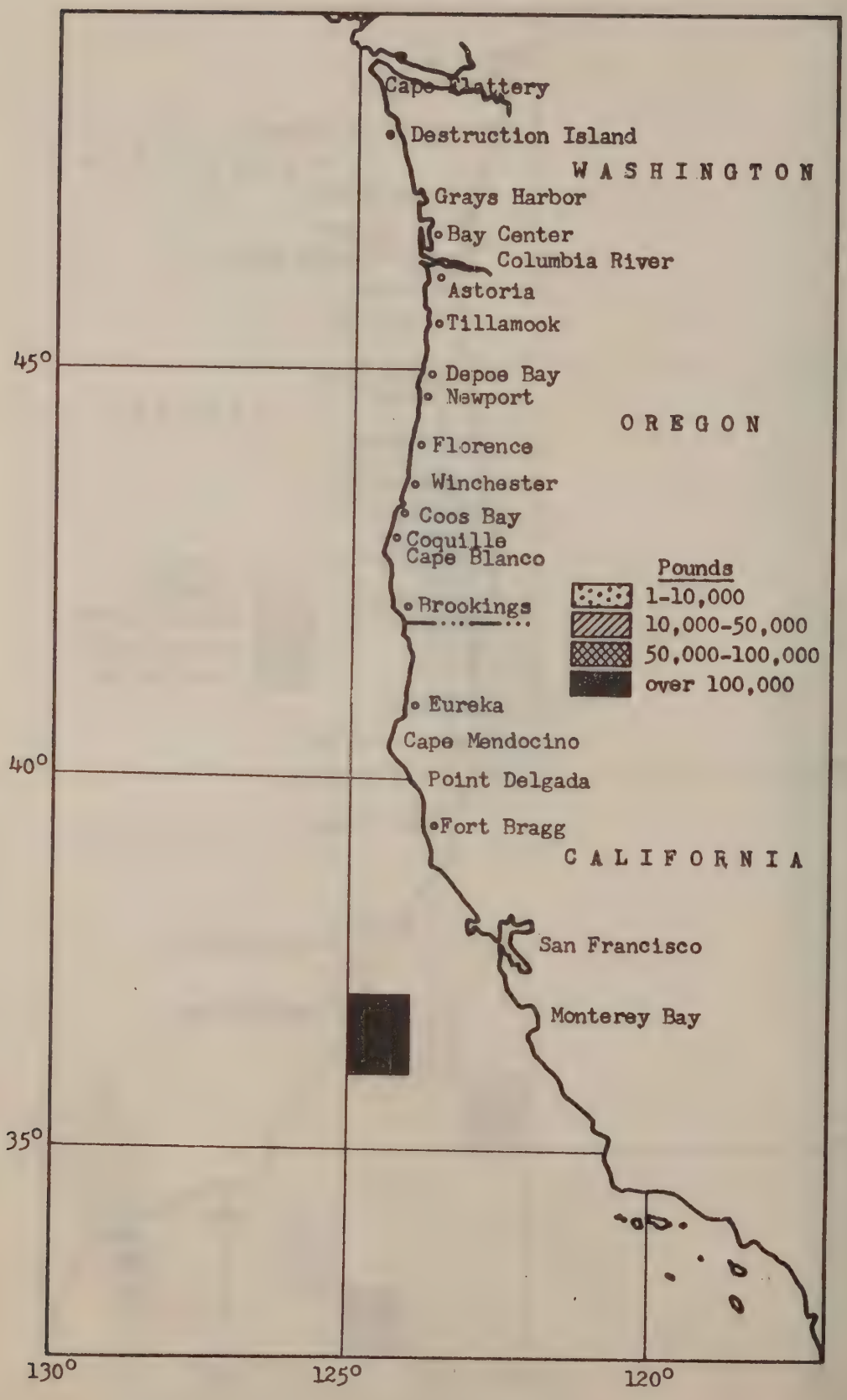


Figure 17
Catch Localities for Pacific Albacore
August 1956

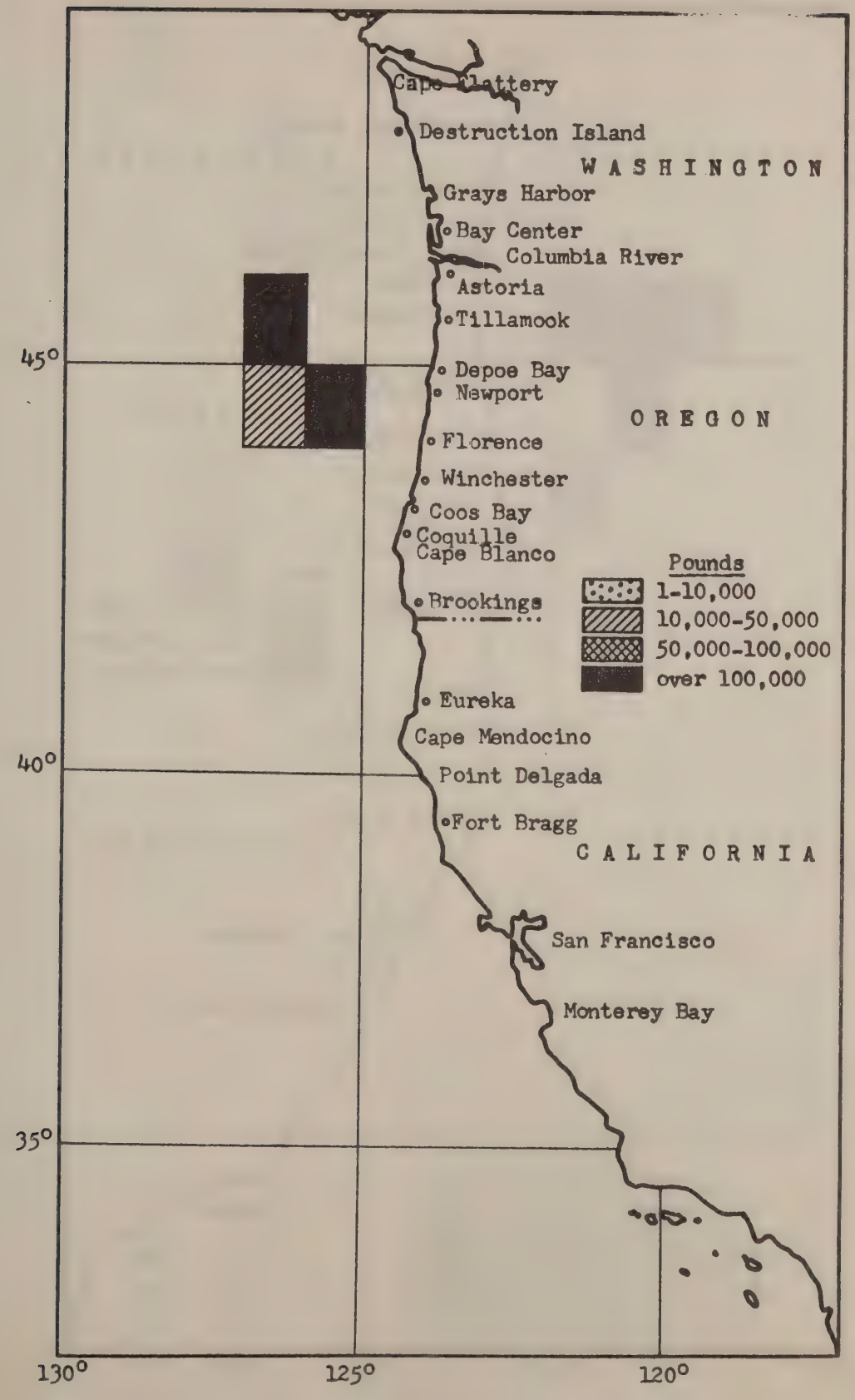


Figure 18
Catch Localities for Pacific Albacore
September 1956

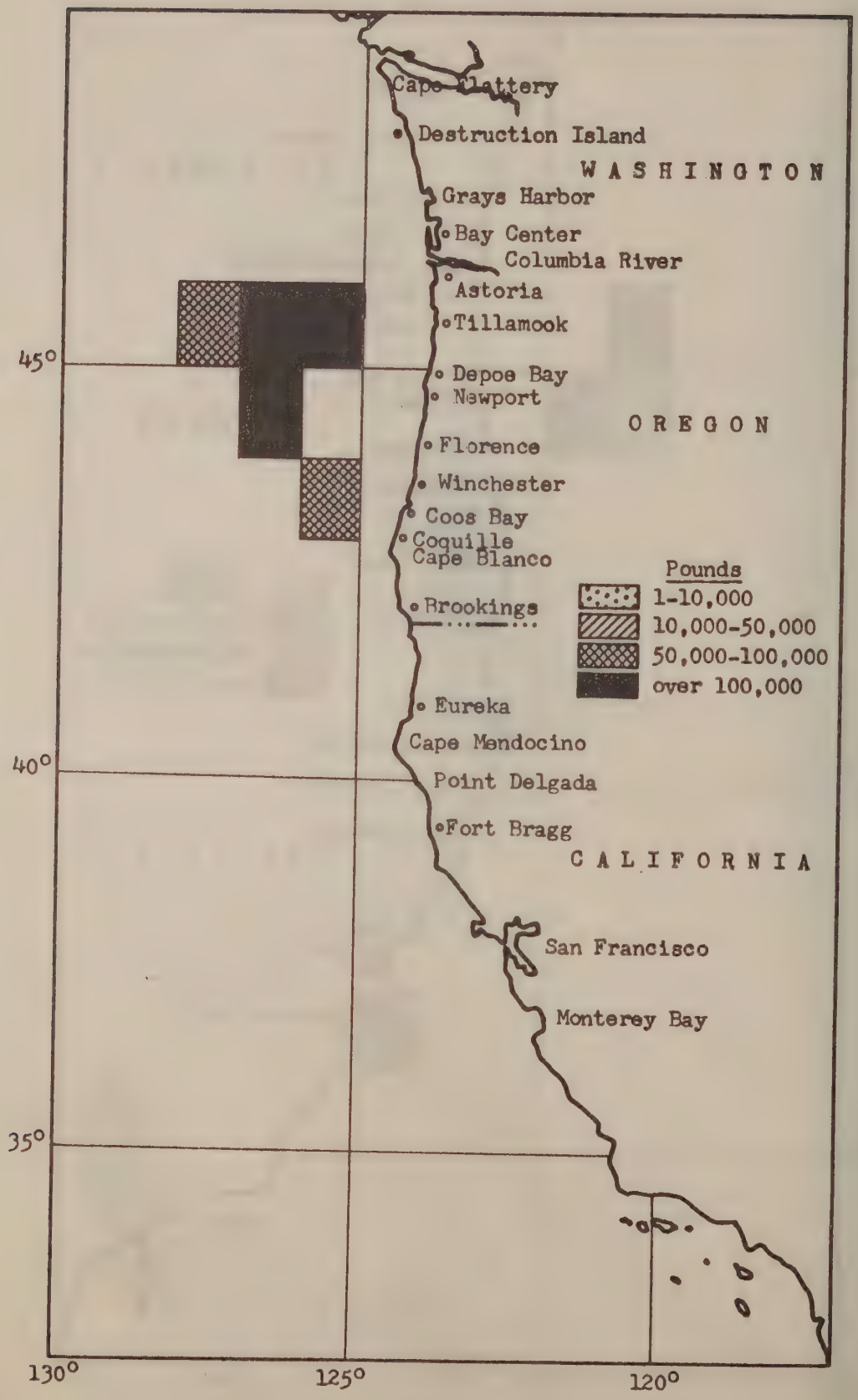


Figure 19
Catch Localities for Pacific Albacore
July 1957

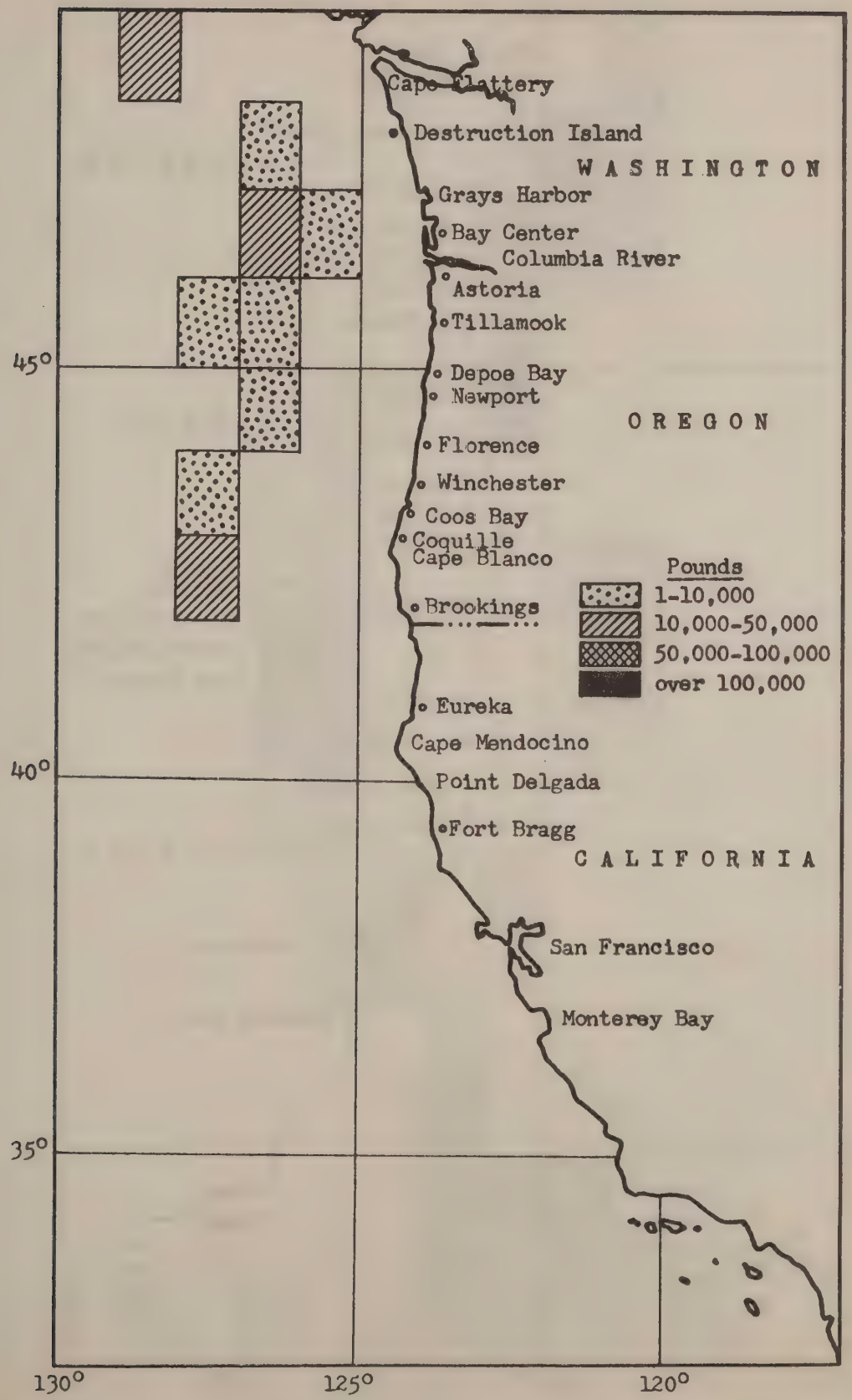


Figure 20
Catch Localities for Pacific Albacore
August 1957

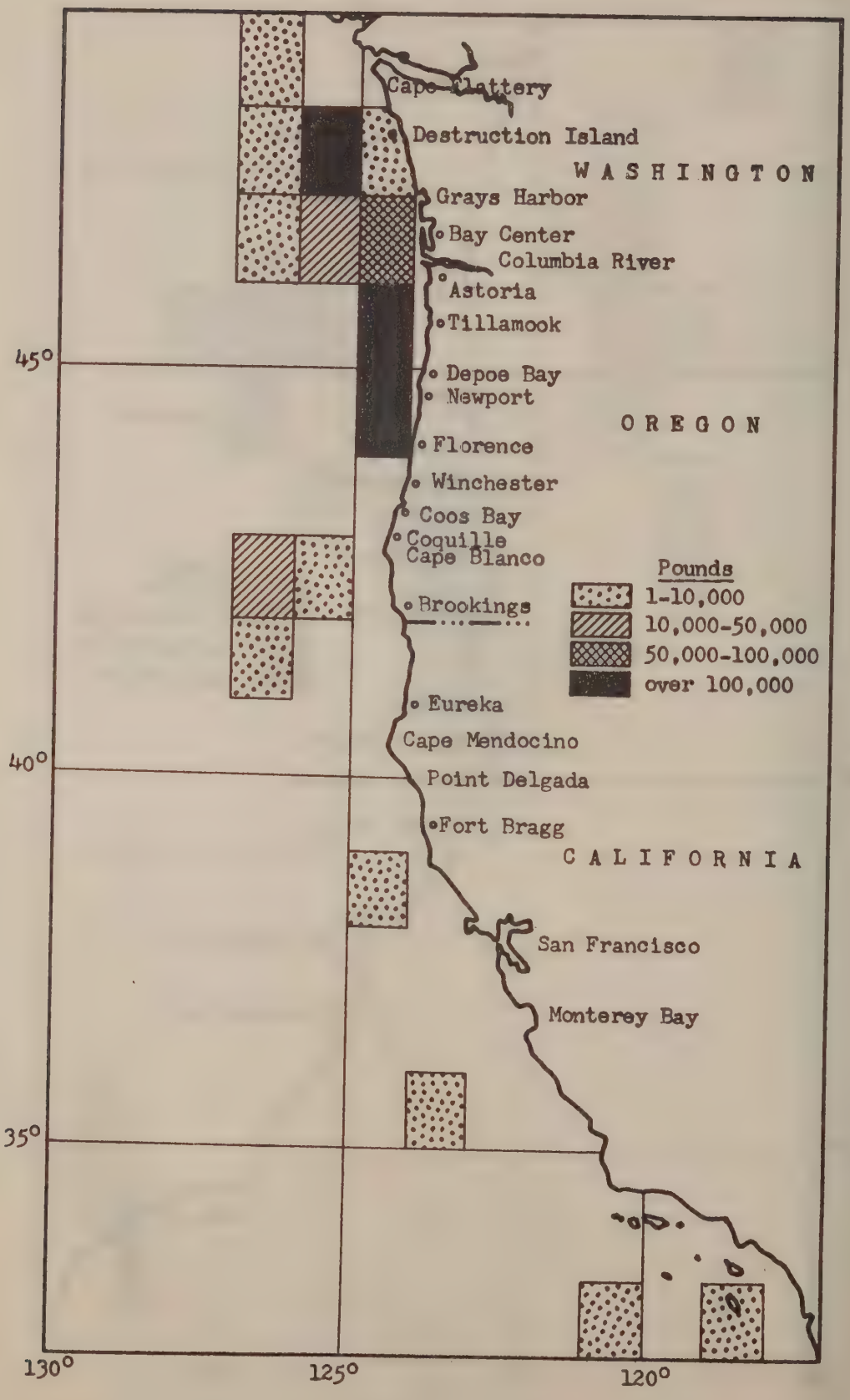


Figure 21
Catch Localities for Pacific Albacore
September 1957

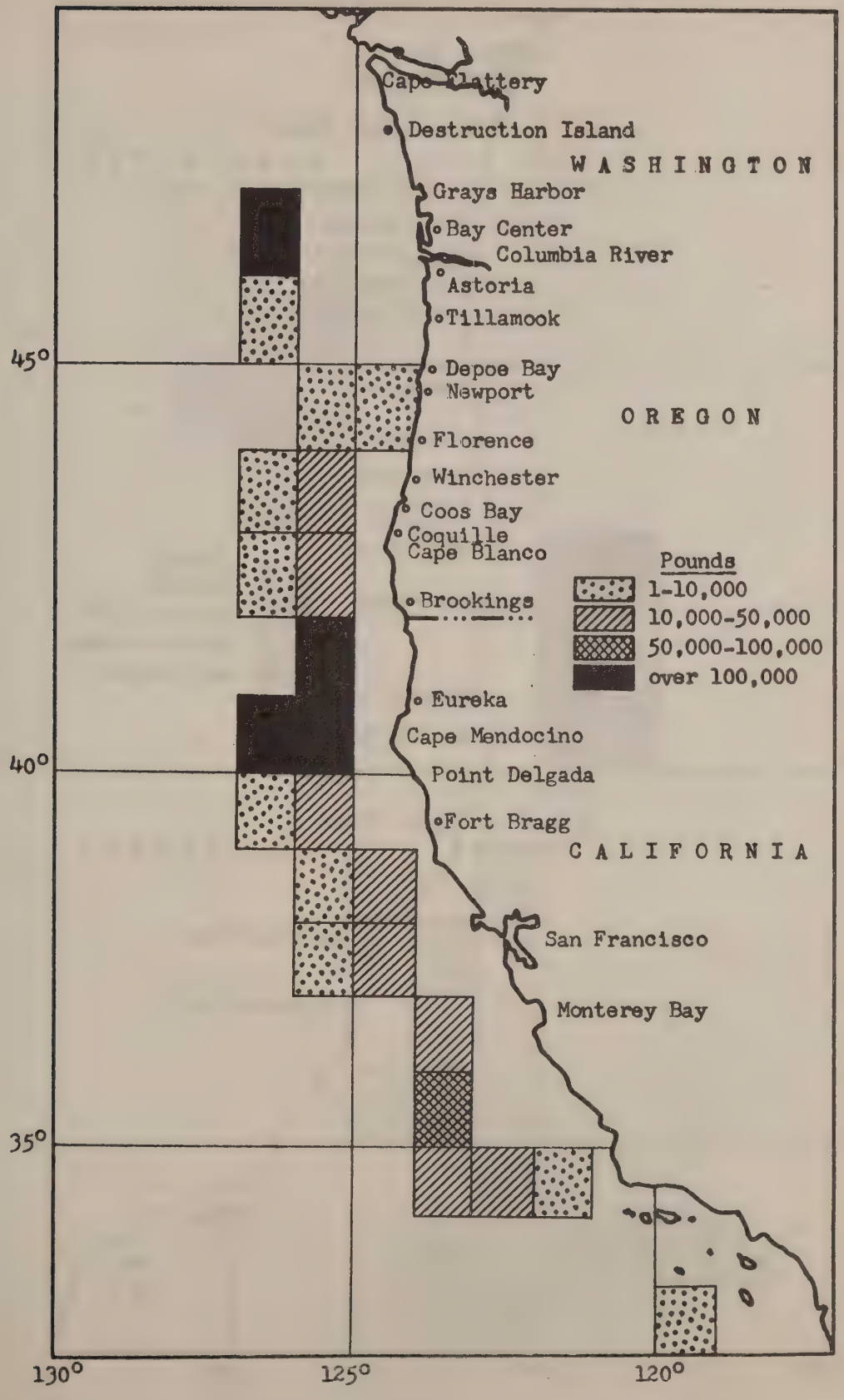


Figure 22
Catch Localities for Pacific Albacore
October 1957

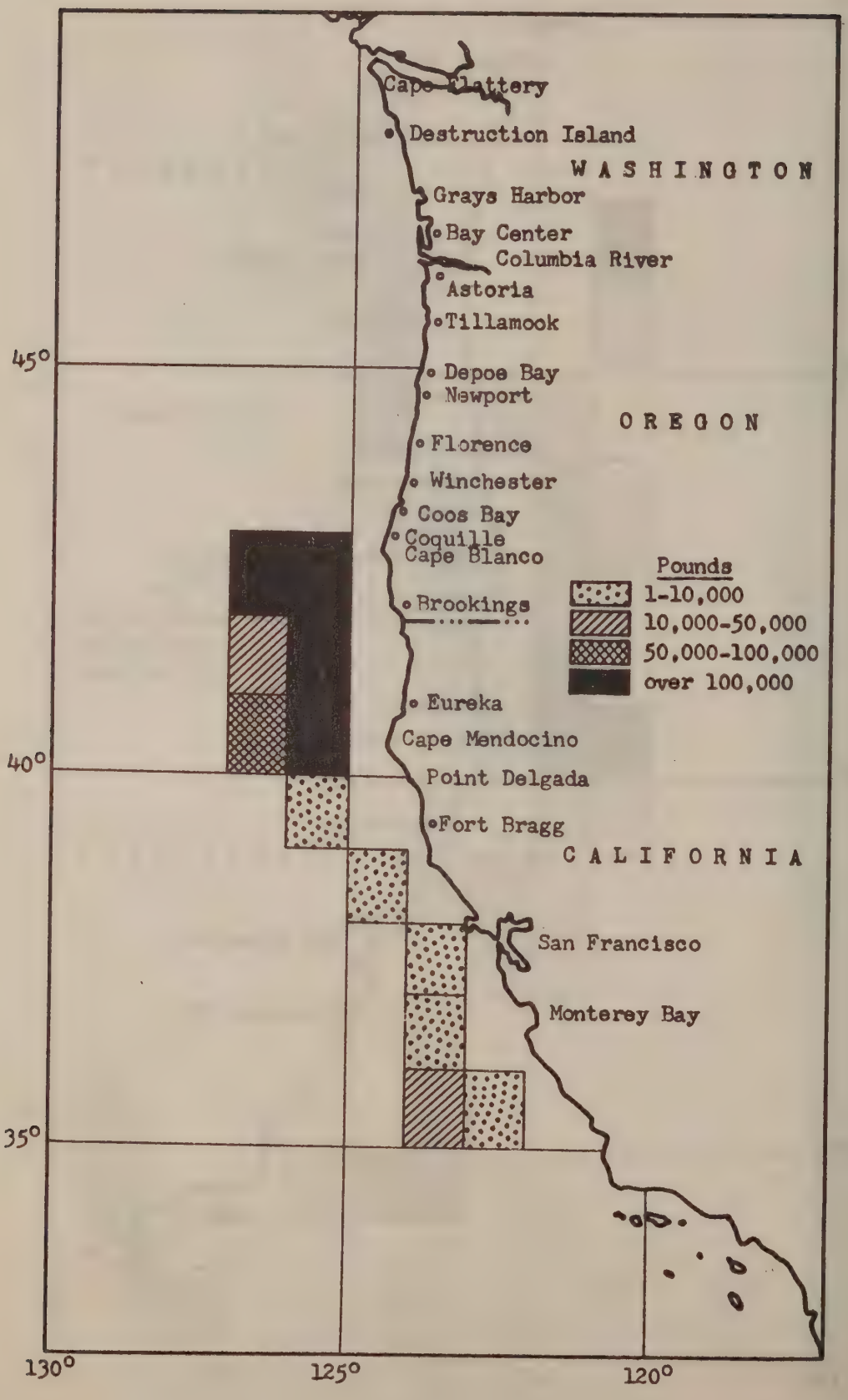


Figure 23
Catch Localities for Pacific Albacore
July 1958

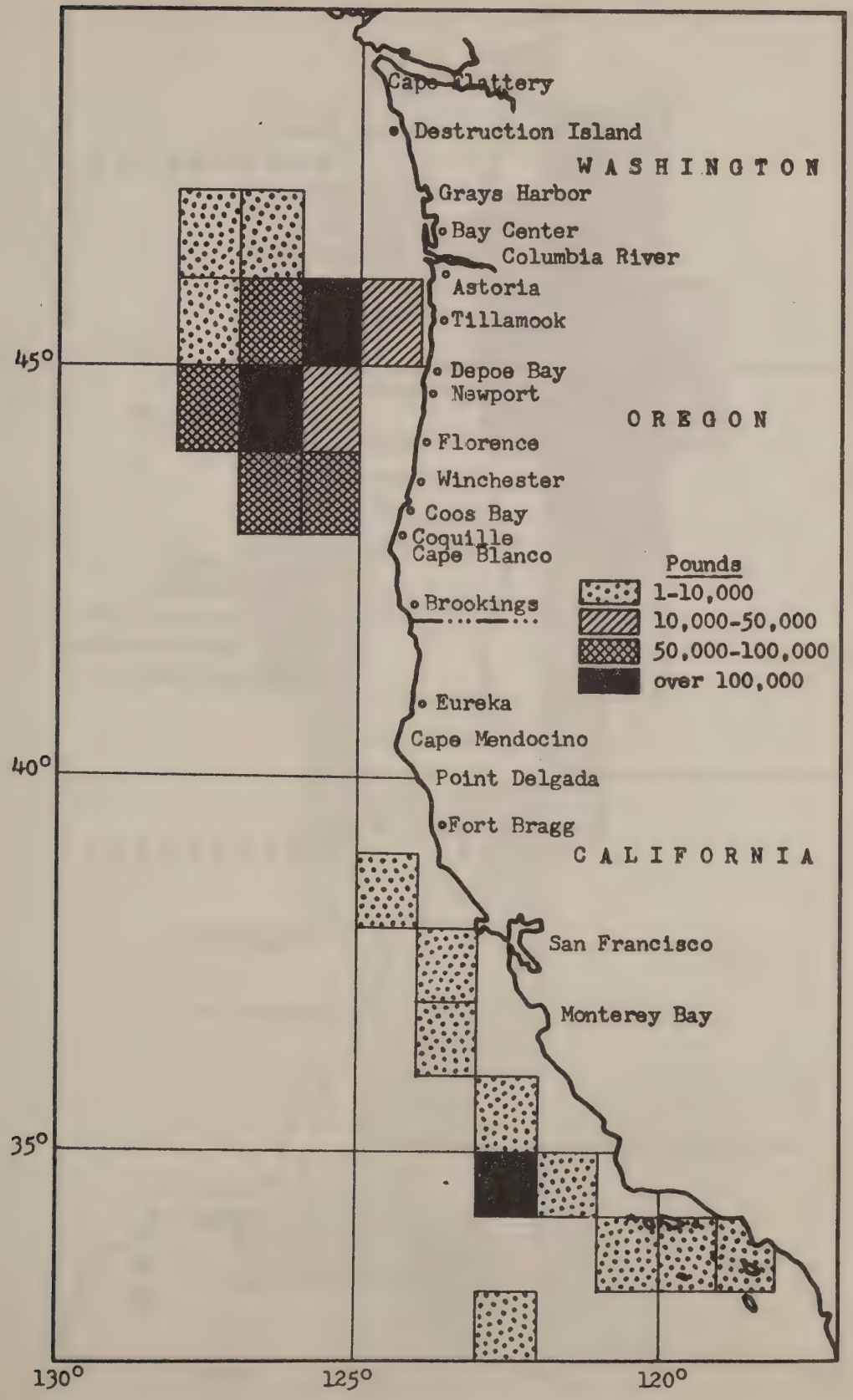


Figure 24
Catch Localities for Pacific Albacore
August 1958

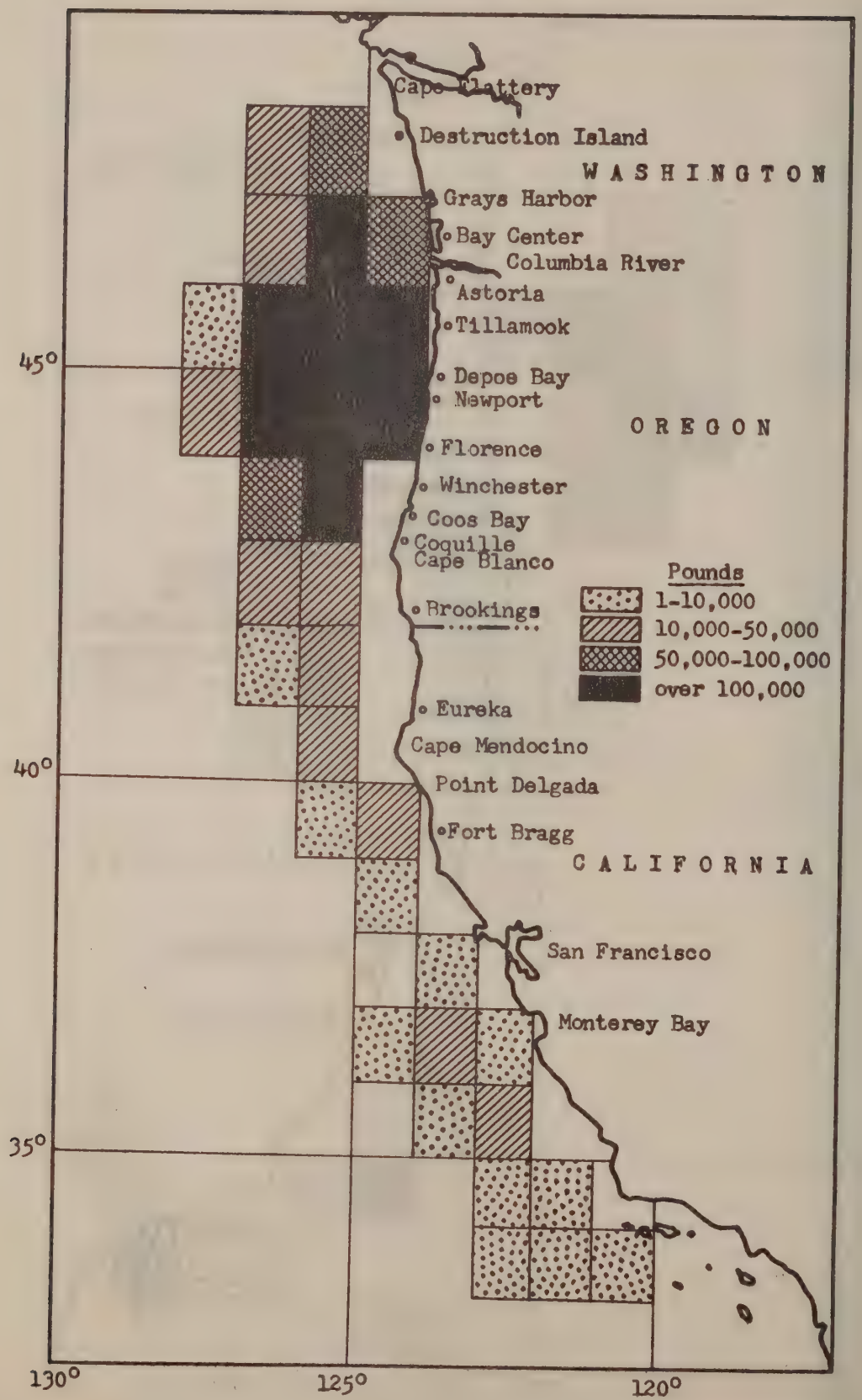


Figure 25
Catch Localities for Pacific Albacore
September 1958

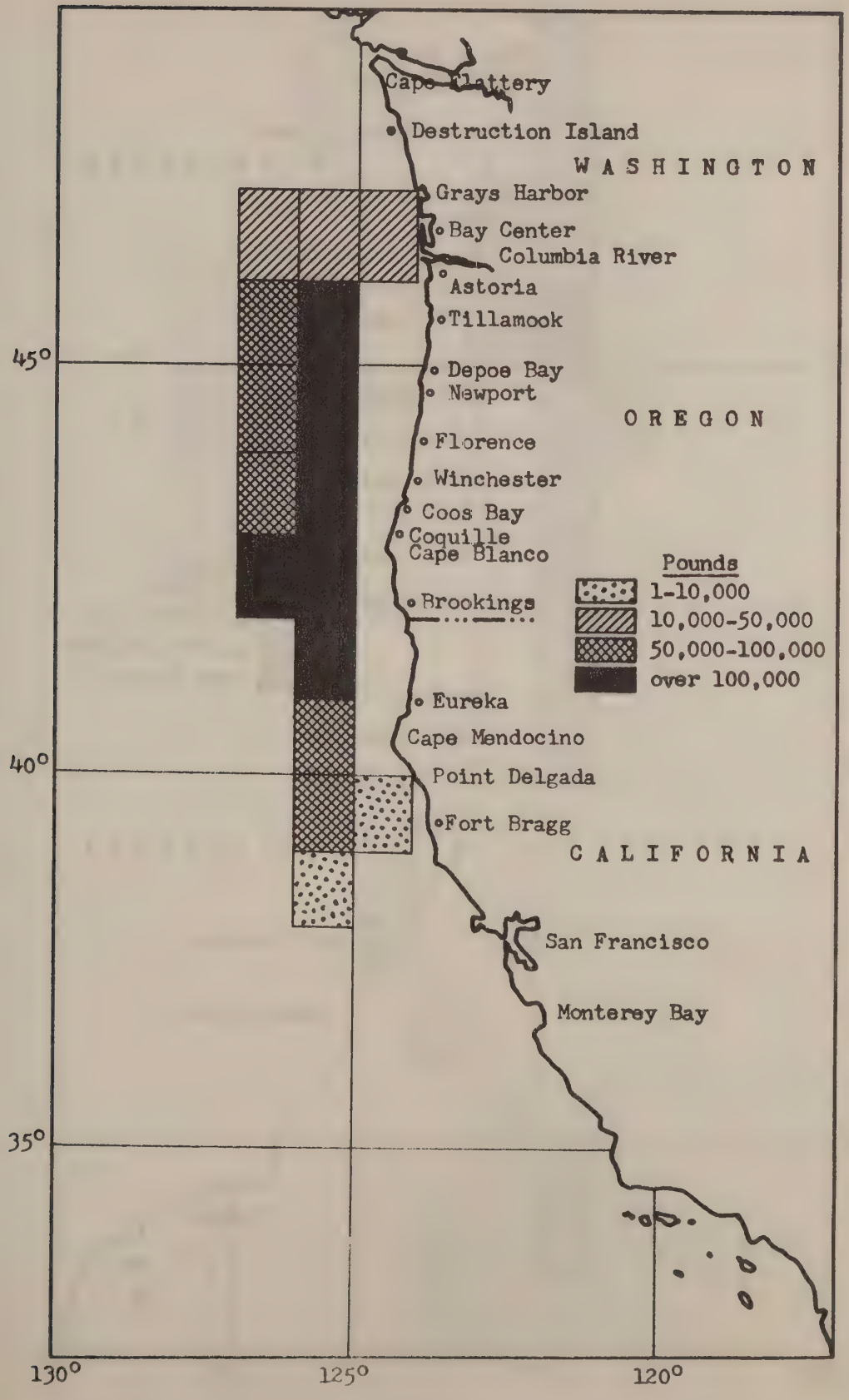


Figure 26
Catch Localities for Pacific Albacore
October 1958

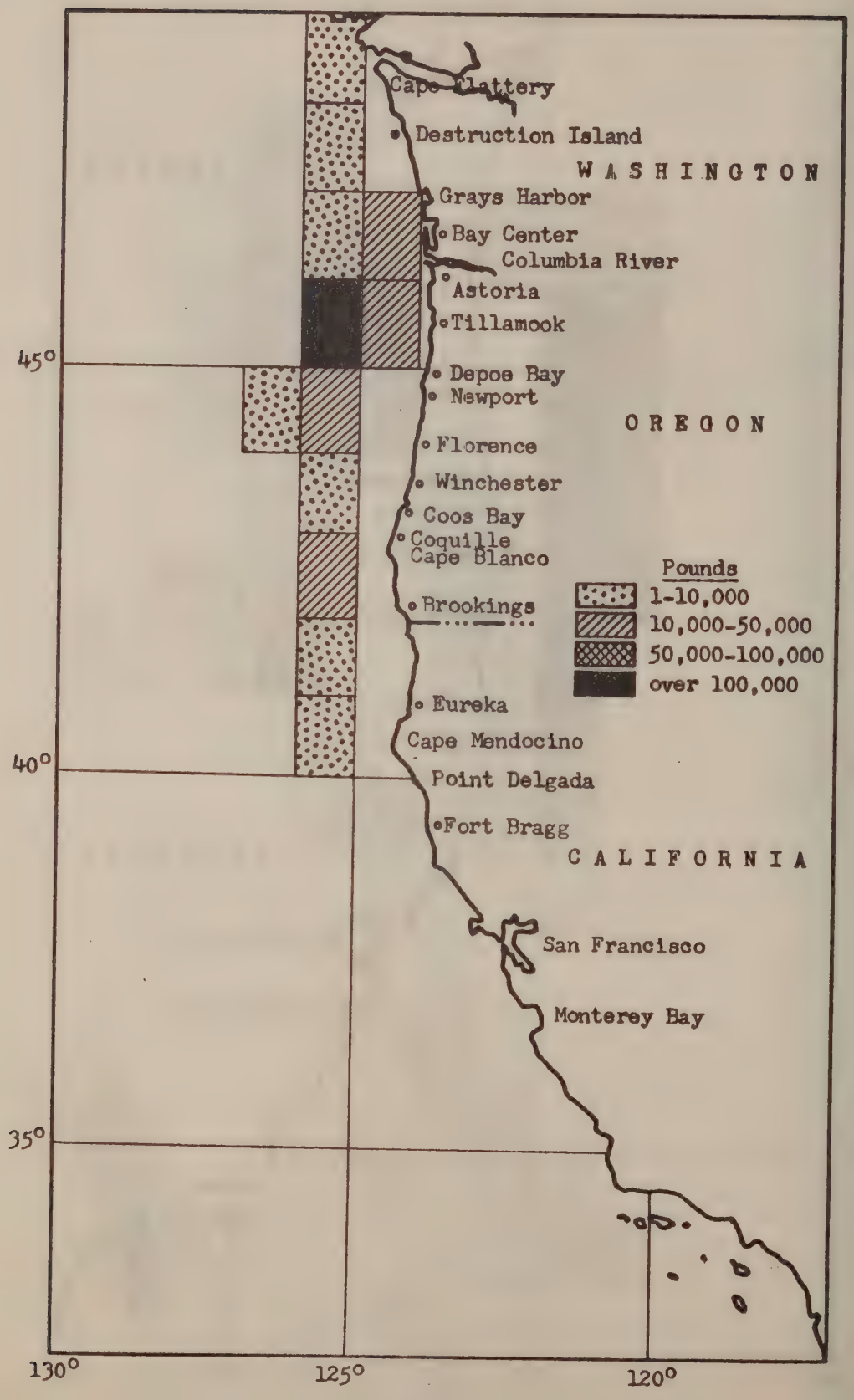


Figure 27
Catch Localities for Pacific Albacore
July 1959

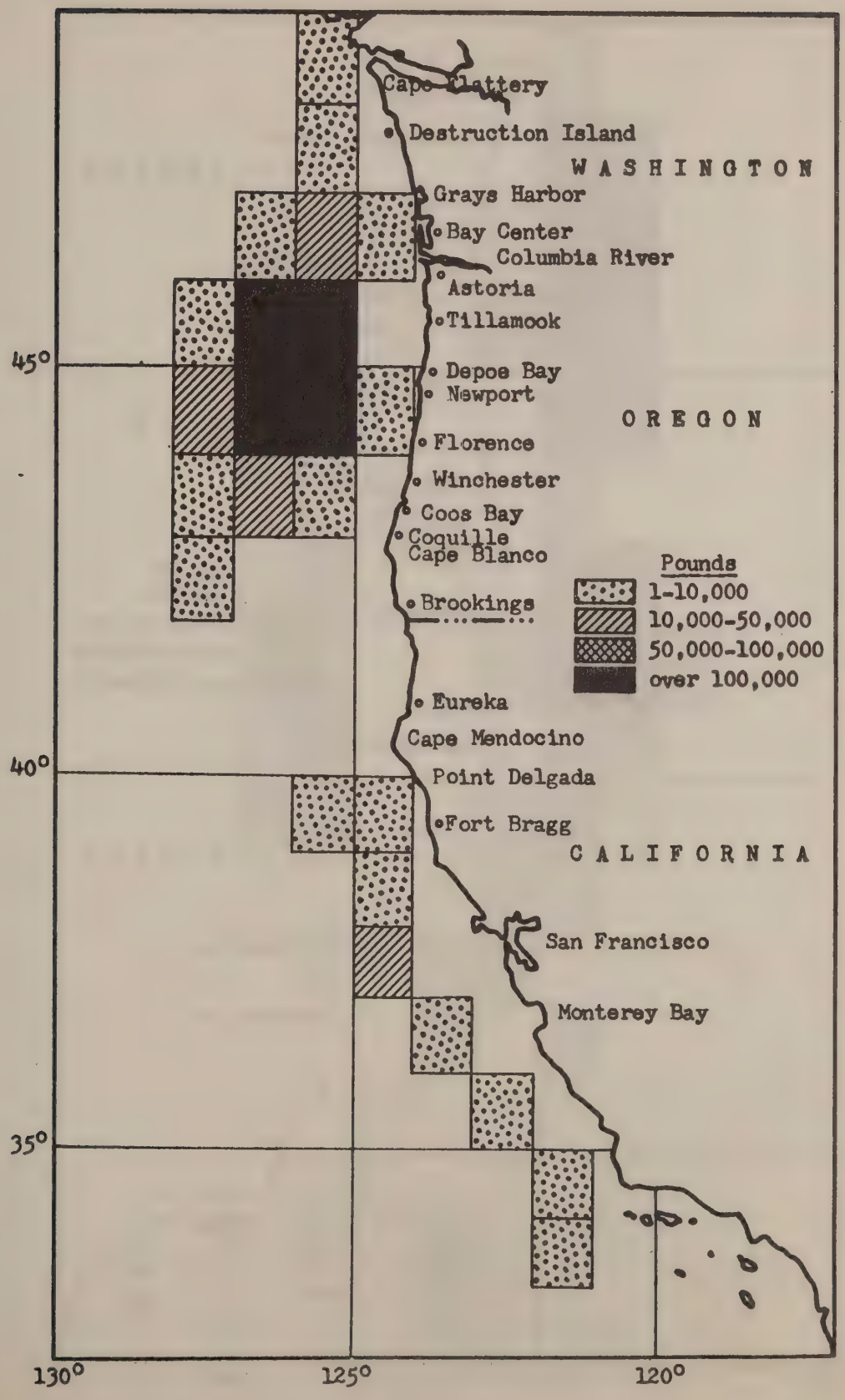


Figure 28
Catch Localities for Pacific Albacore
August 1959

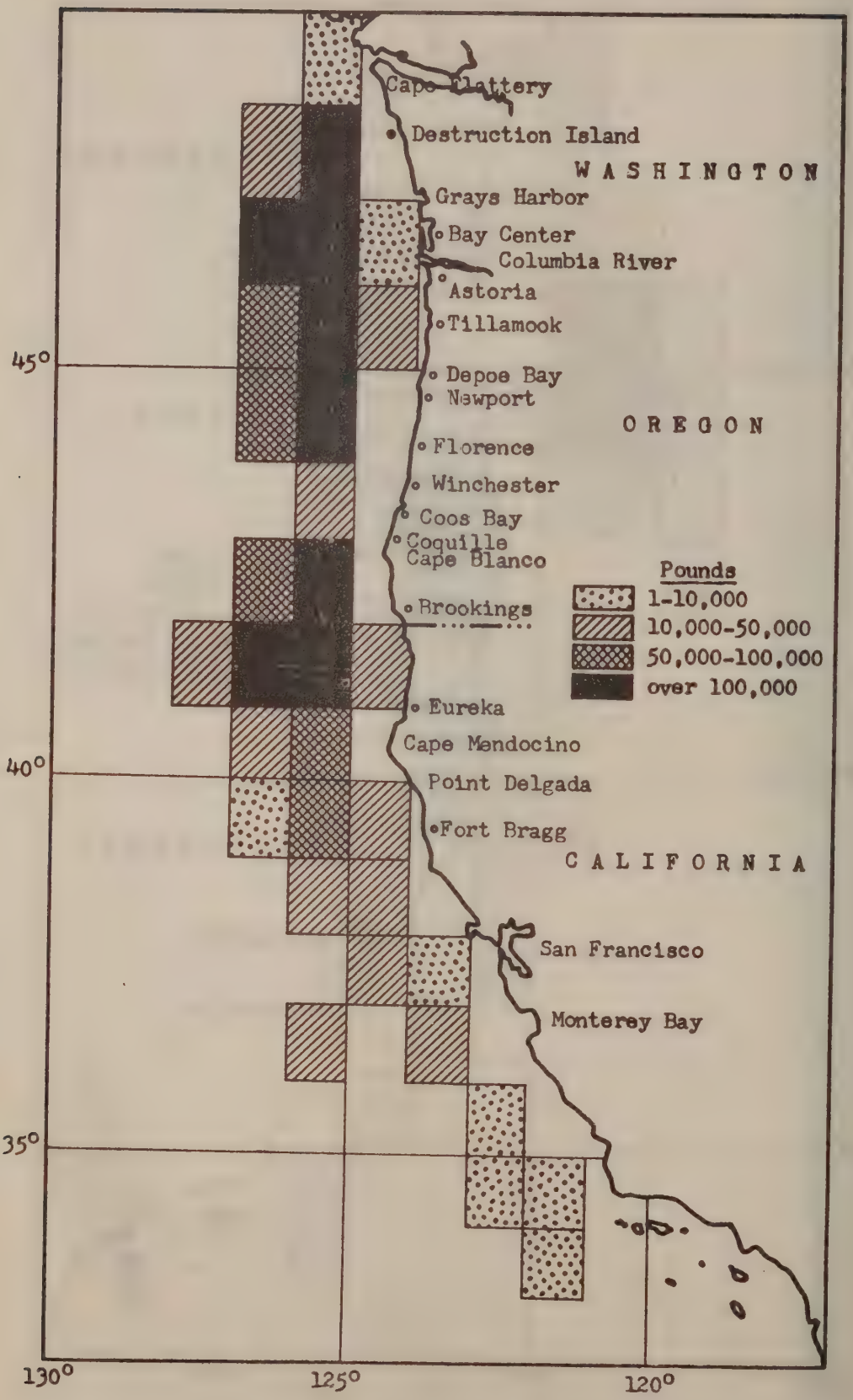


Figure 29
Catch Localities for Pacific Albacore
September 1959

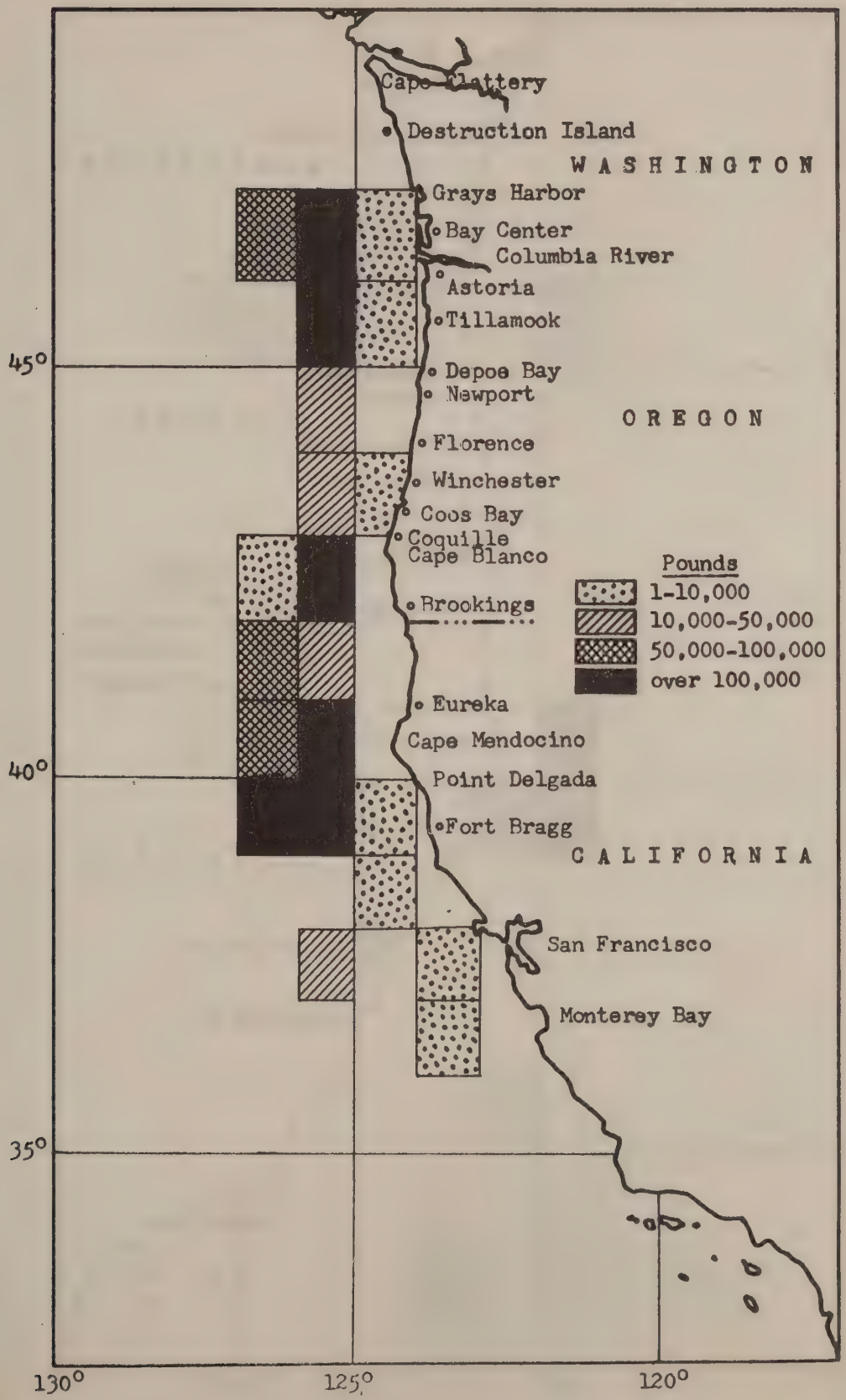


Figure 30
Catch Localities for Pacific Albacore
October 1959

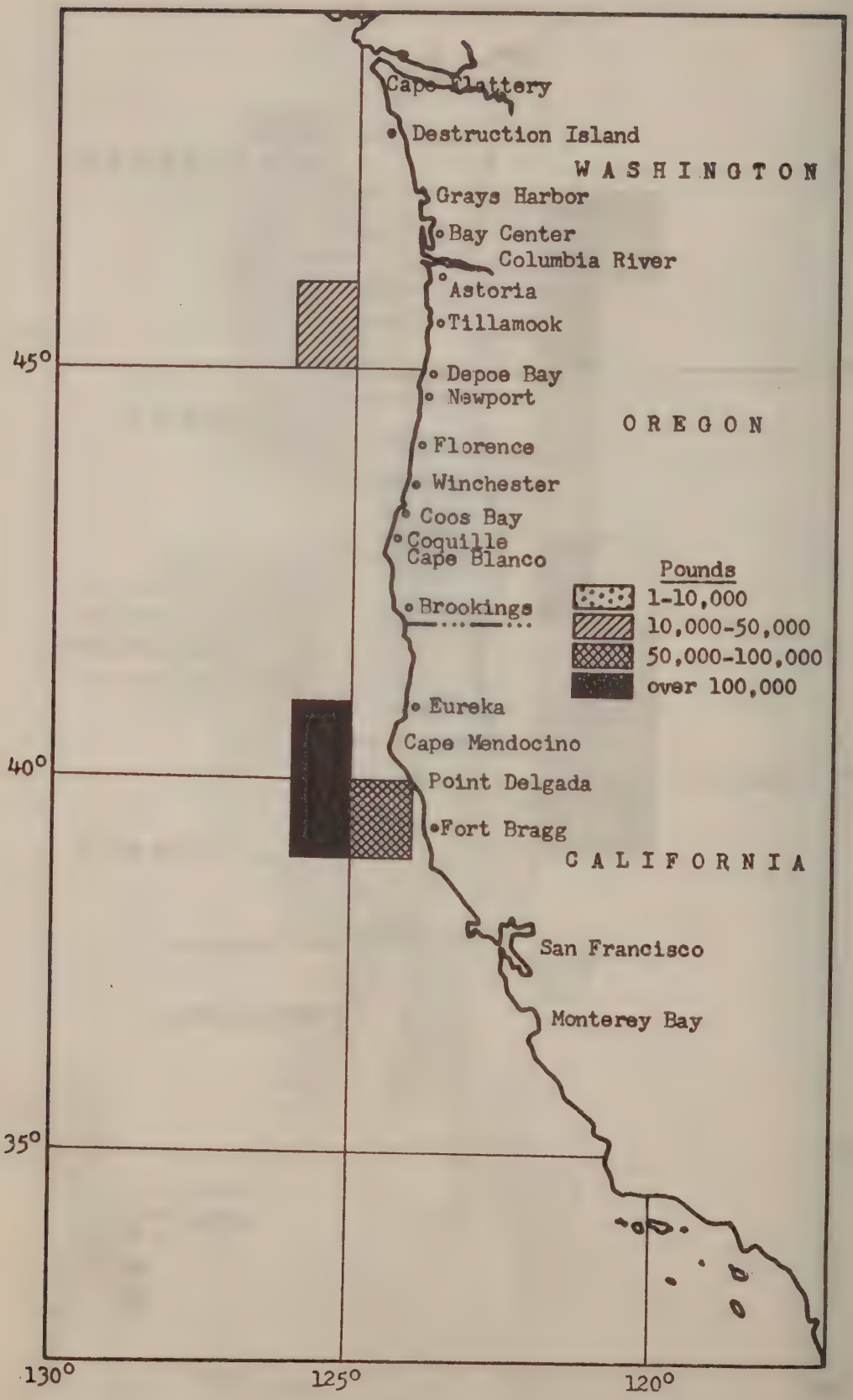


Figure 31
Catch Localities for Pacific Albacore
July 1960

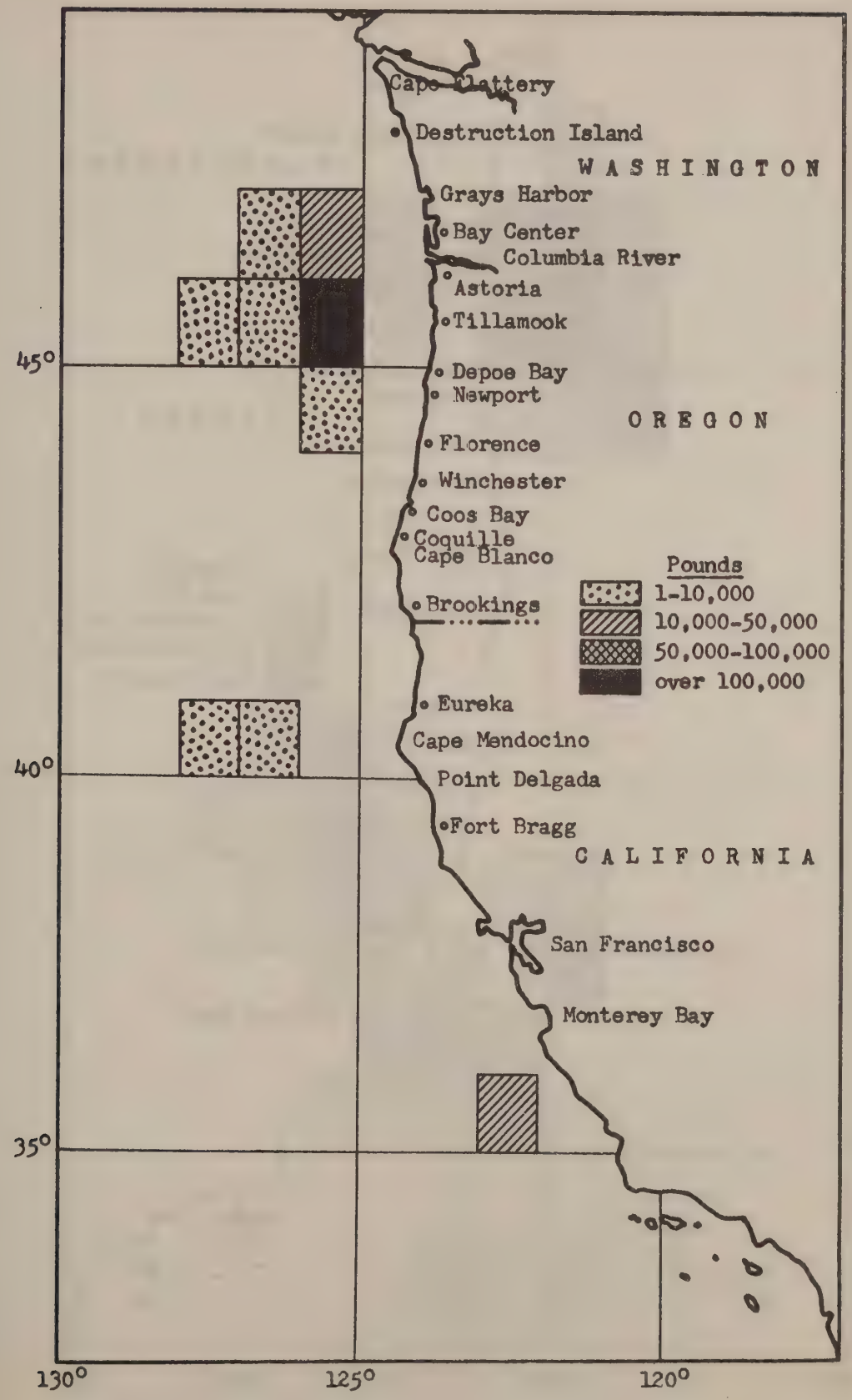


Figure 32
Catch Localities for Pacific Albacore
August 1960

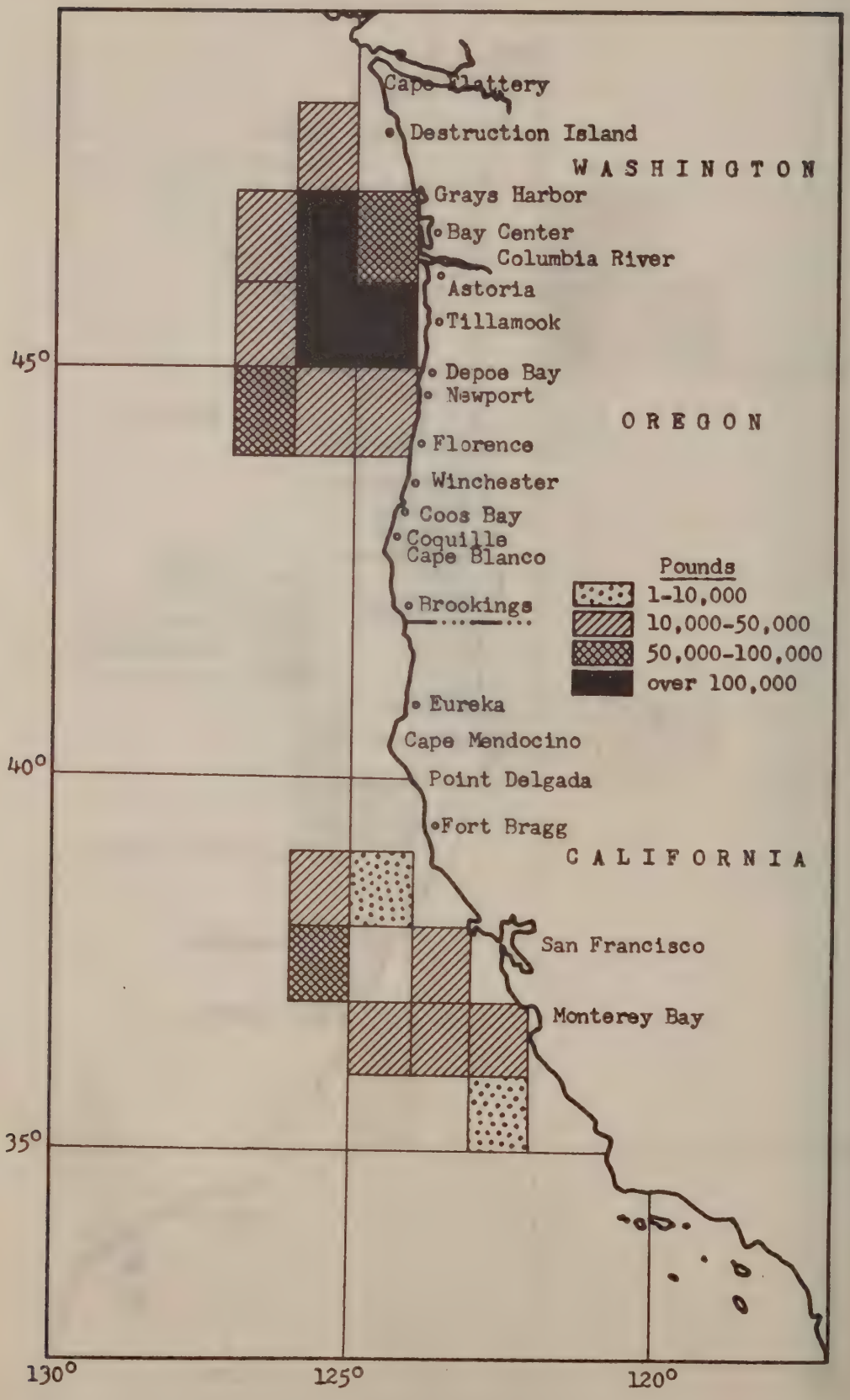


Figure 33
Catch Localities for Pacific Albacore
September 1960

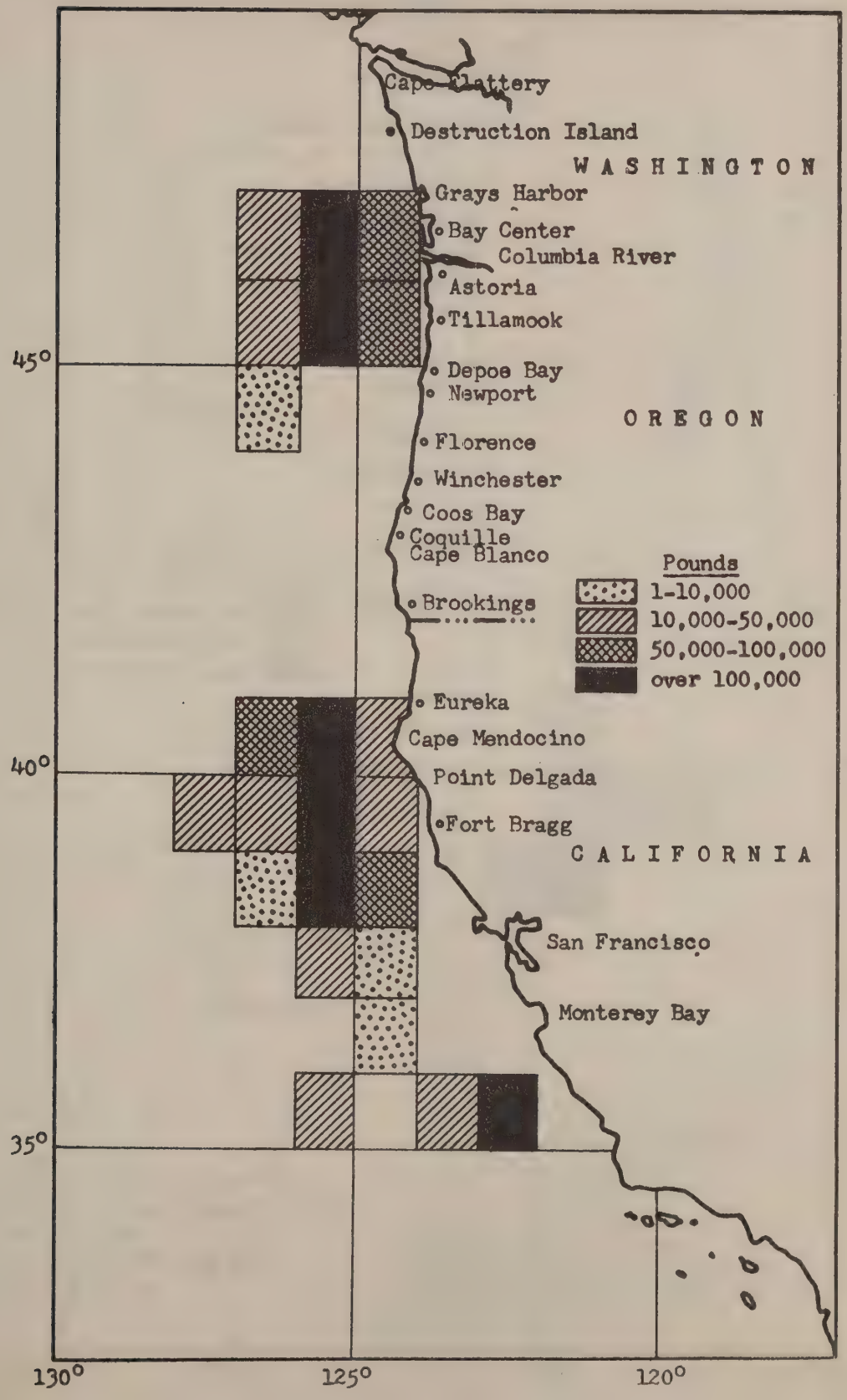


Figure 34
Catch Localities for Pacific Albacore
October 1960

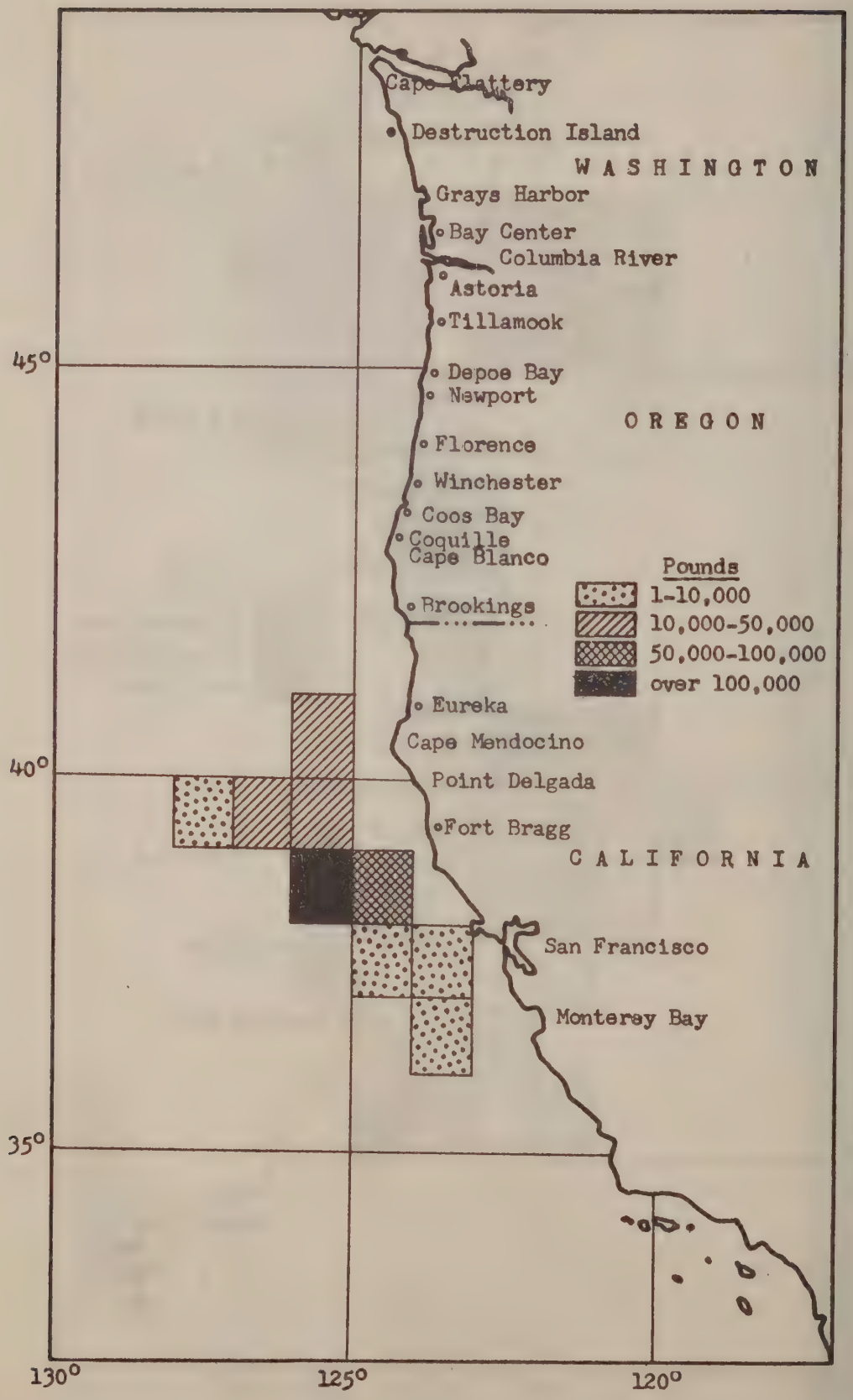


Figure 35
Albacore Length-Frequency Distribution by Month
1939

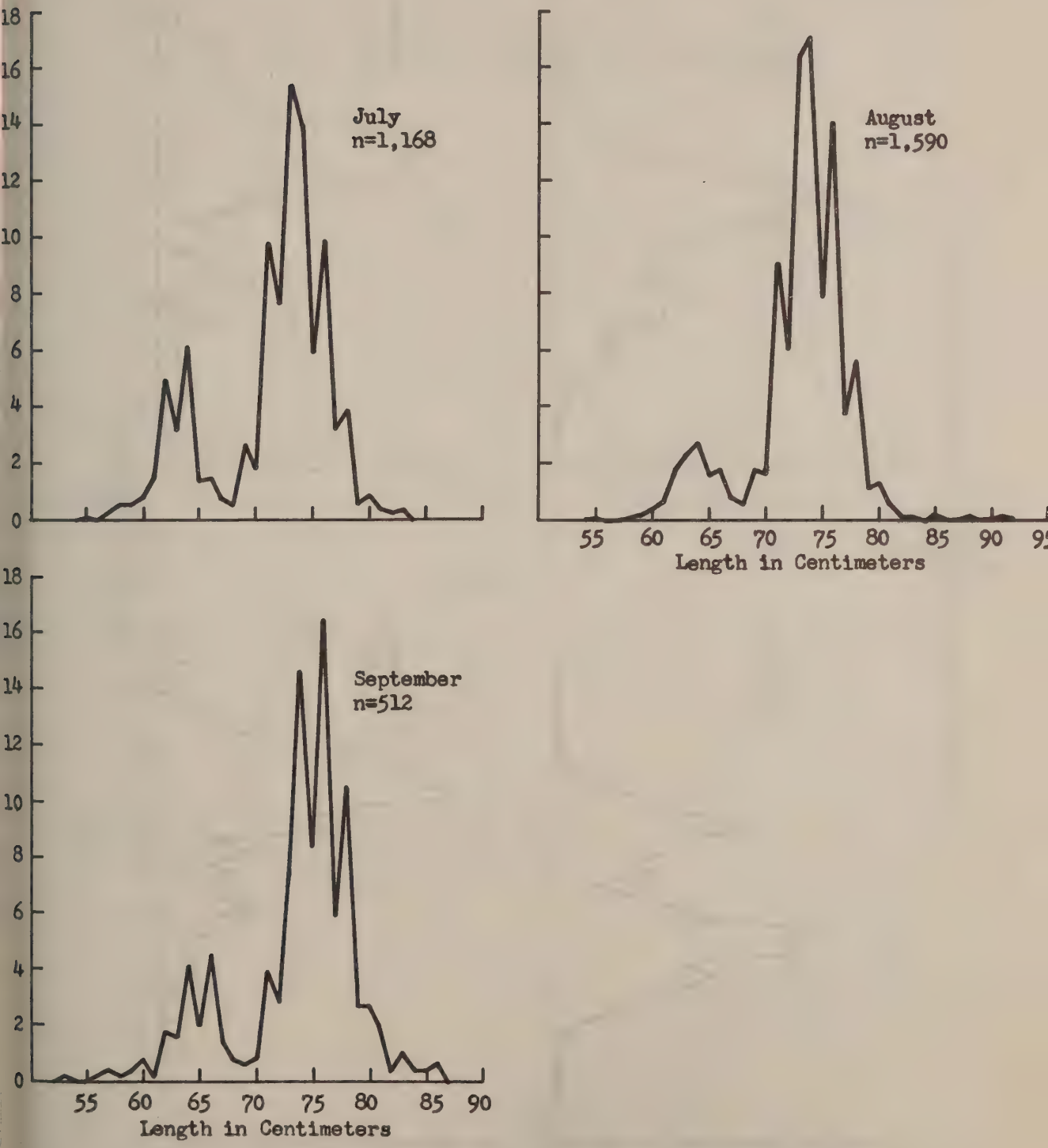


Figure 36
Albacore Length-Frequency Distribution by Month
1940

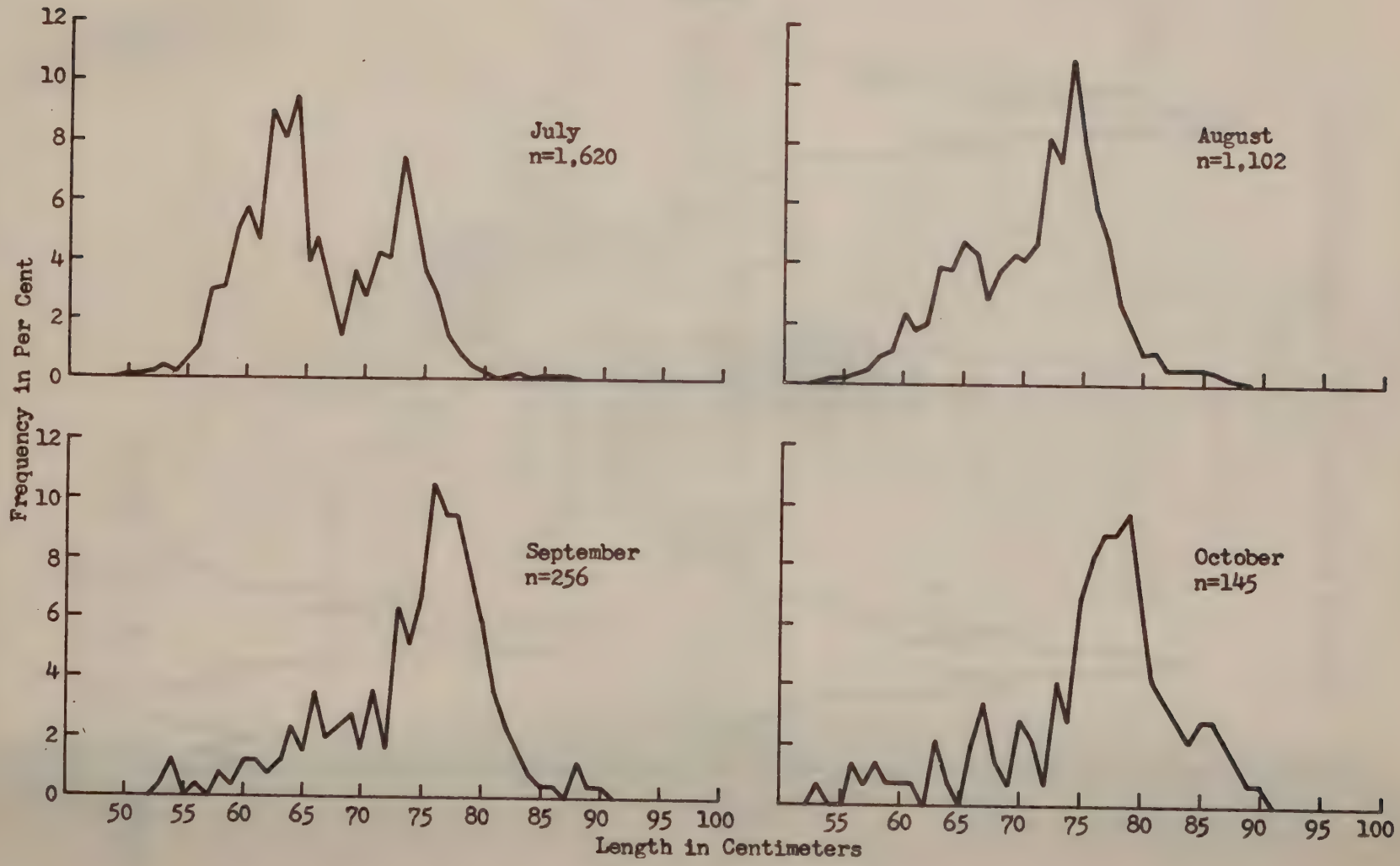


Figure 37
Albacore Length-Frequency Distribution by Month
1941

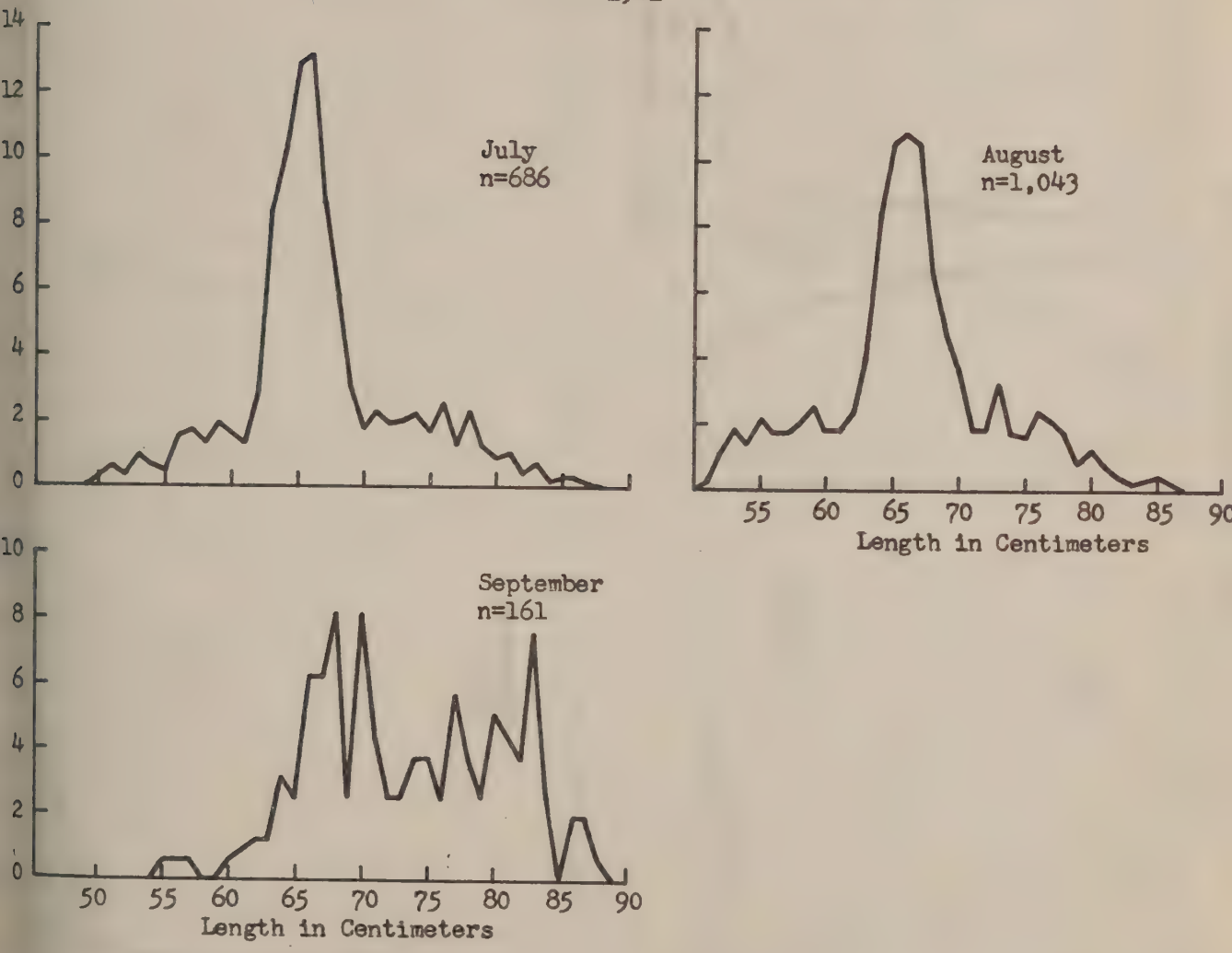
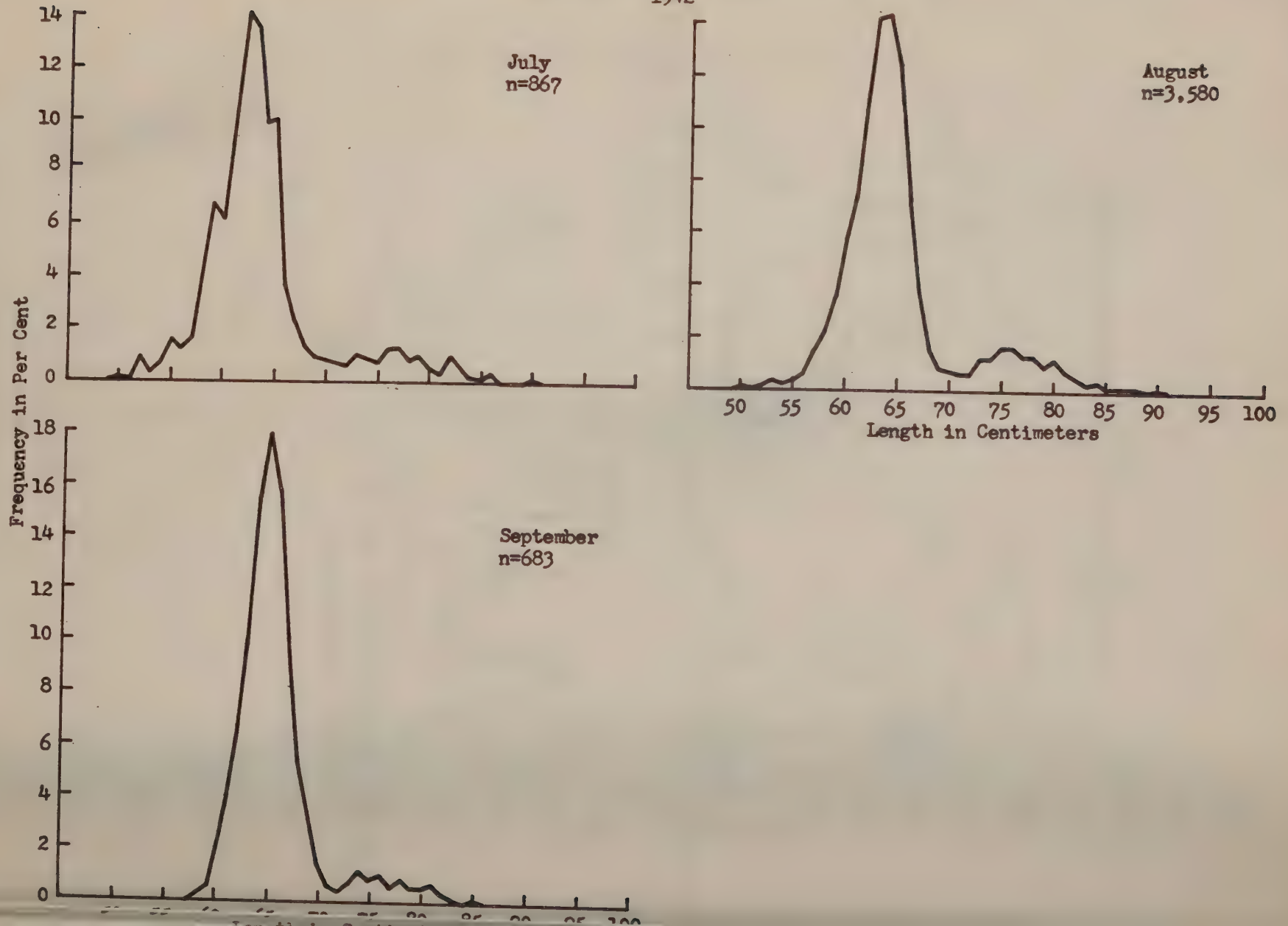


Figure 38
Albacore Length-Frequency Distribution by Month
1942



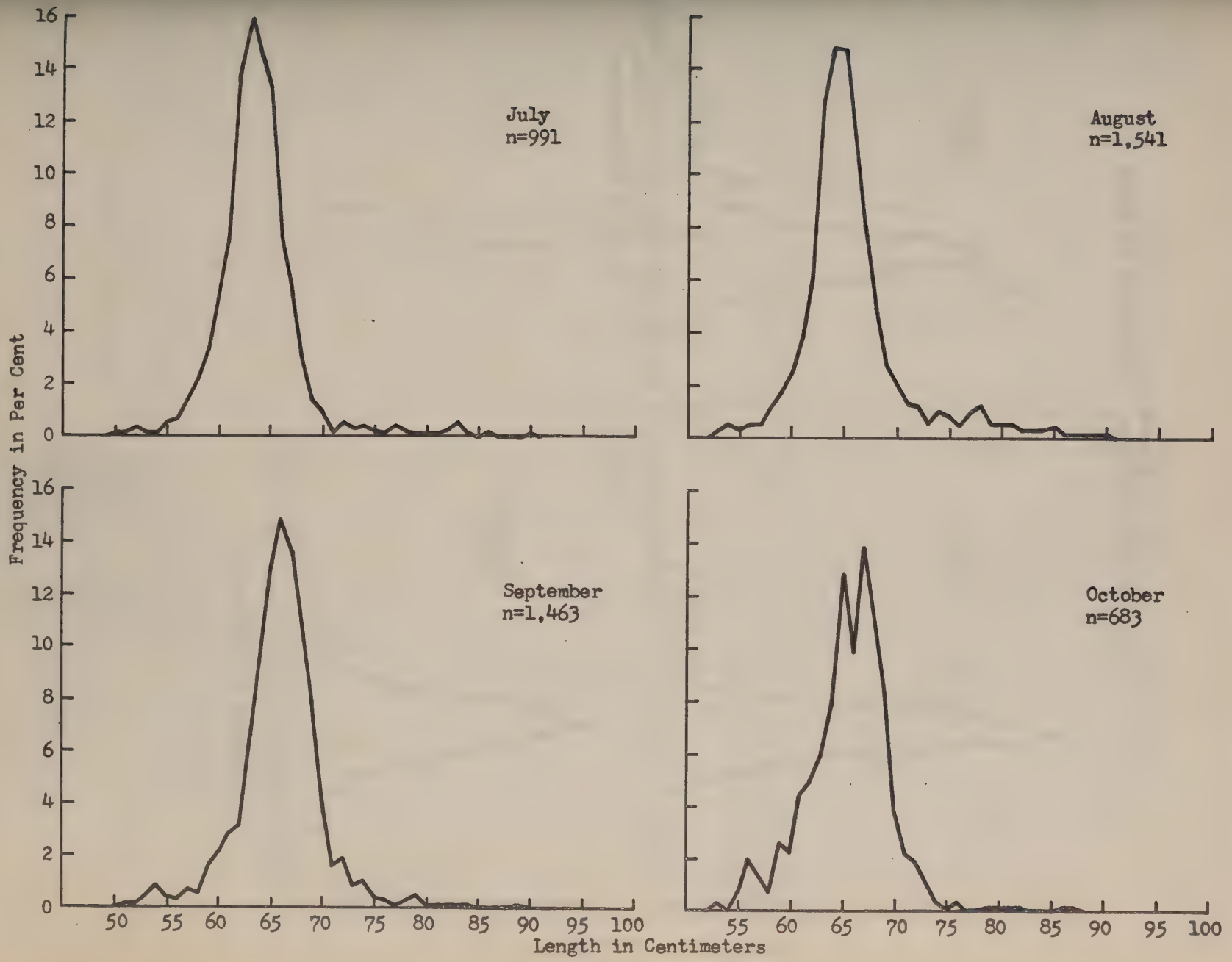

July
n=991
August
n=1,541
September
n=1,463
October
n=683
Frequency in Per Cent
Length in Centimeters
0
2
4
6
8
10
12
14
16
50
55
60
65
70
75
80
85
90
95
100

Figure 40
Albacore Length-Frequency Distribution by Month
1948

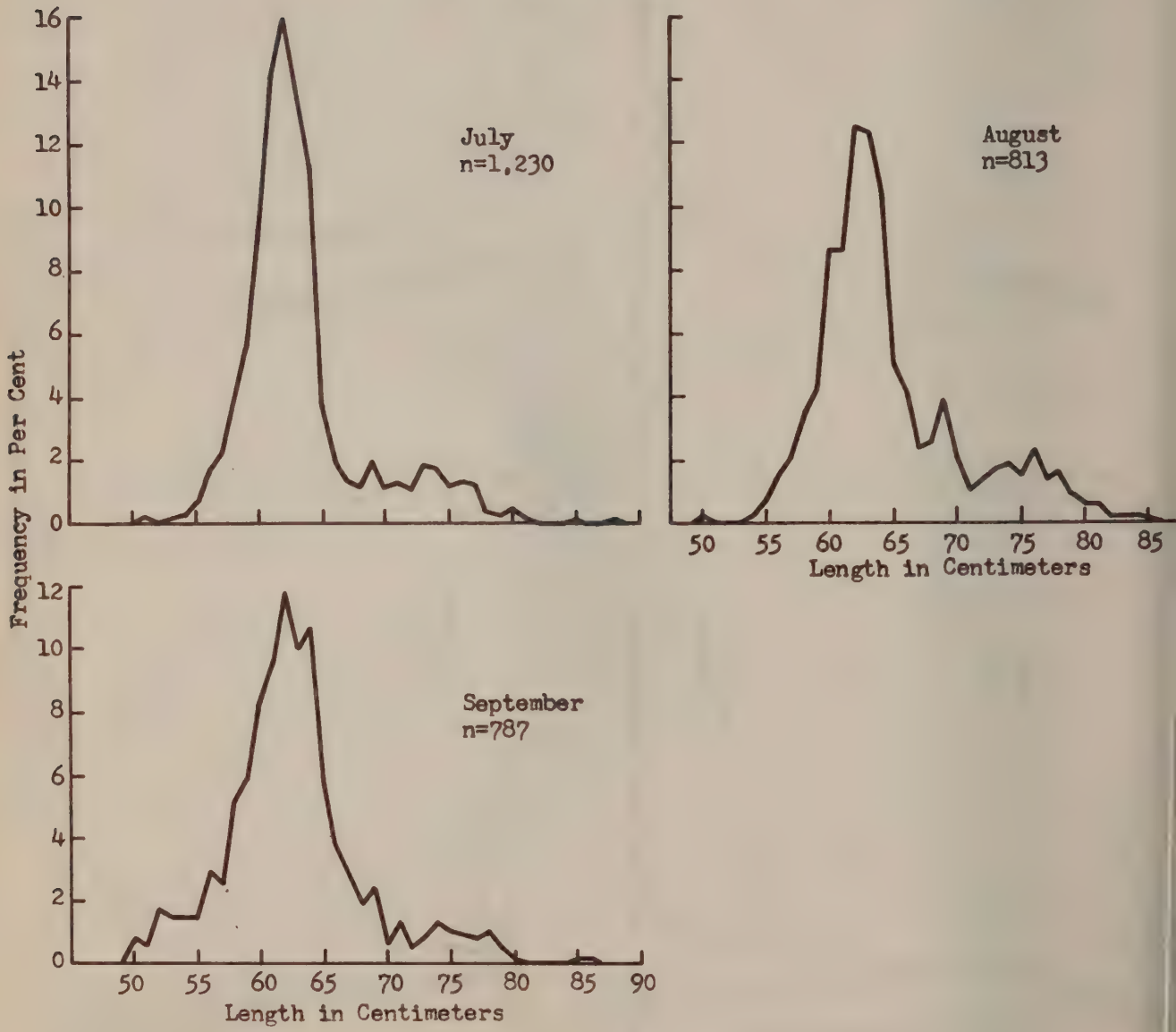


Figure 41
Albacore Length-Frequency Distribution by Month
1949

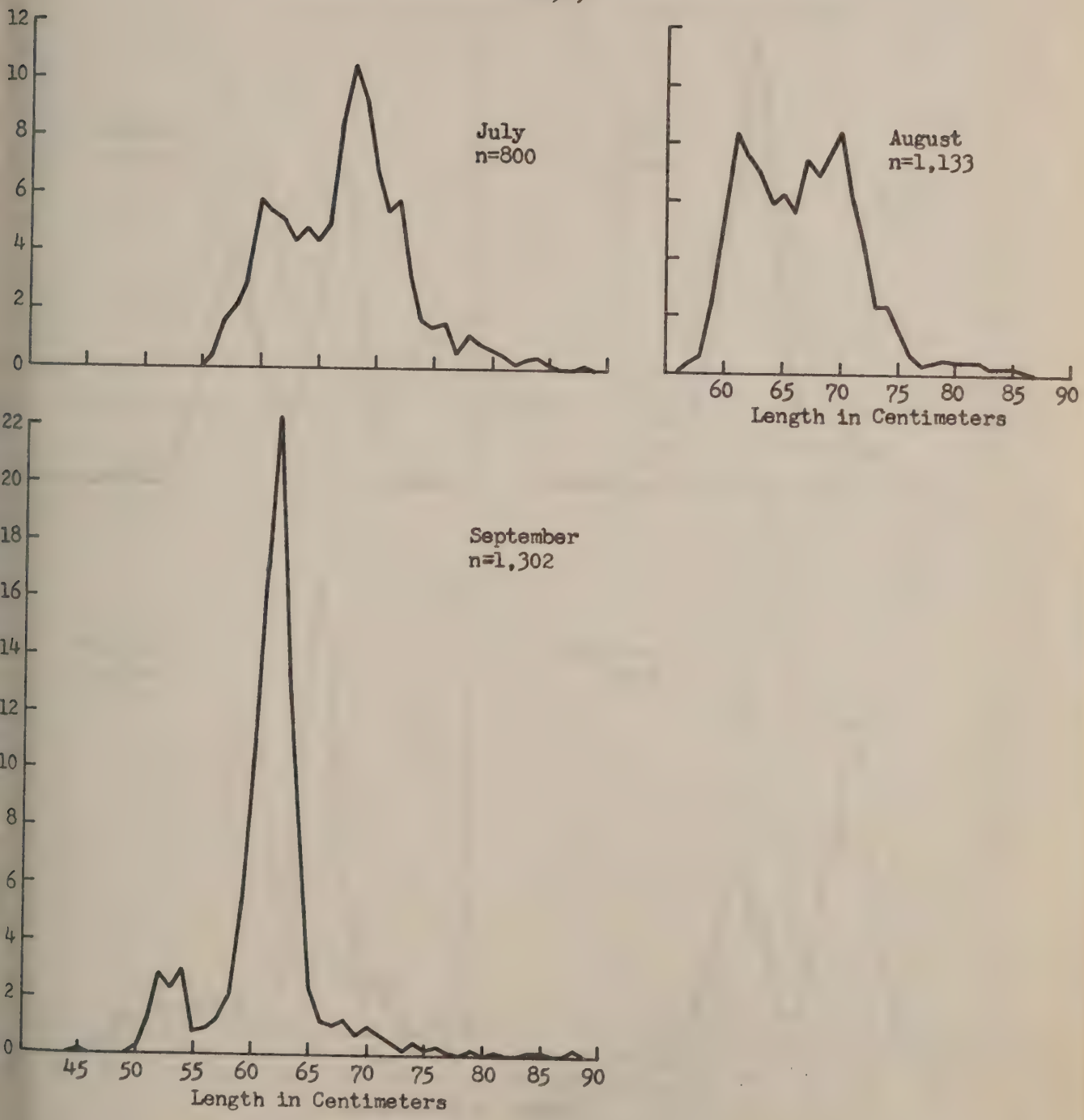


Figure 42
Albacore Length-Frequency Distribution by Month
1950

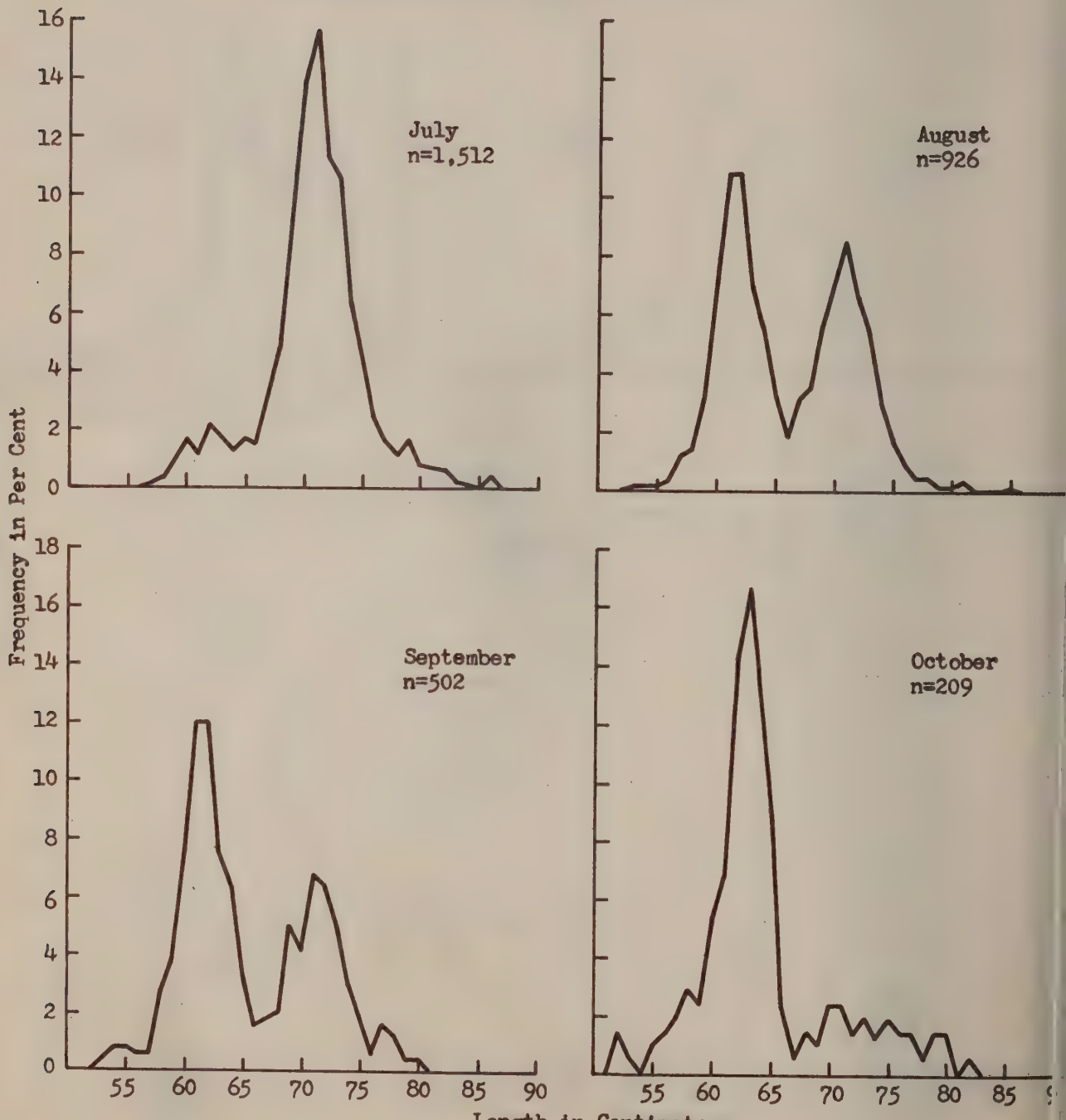


Figure 43
Albacore Length-Frequency Distribution by Month
1951

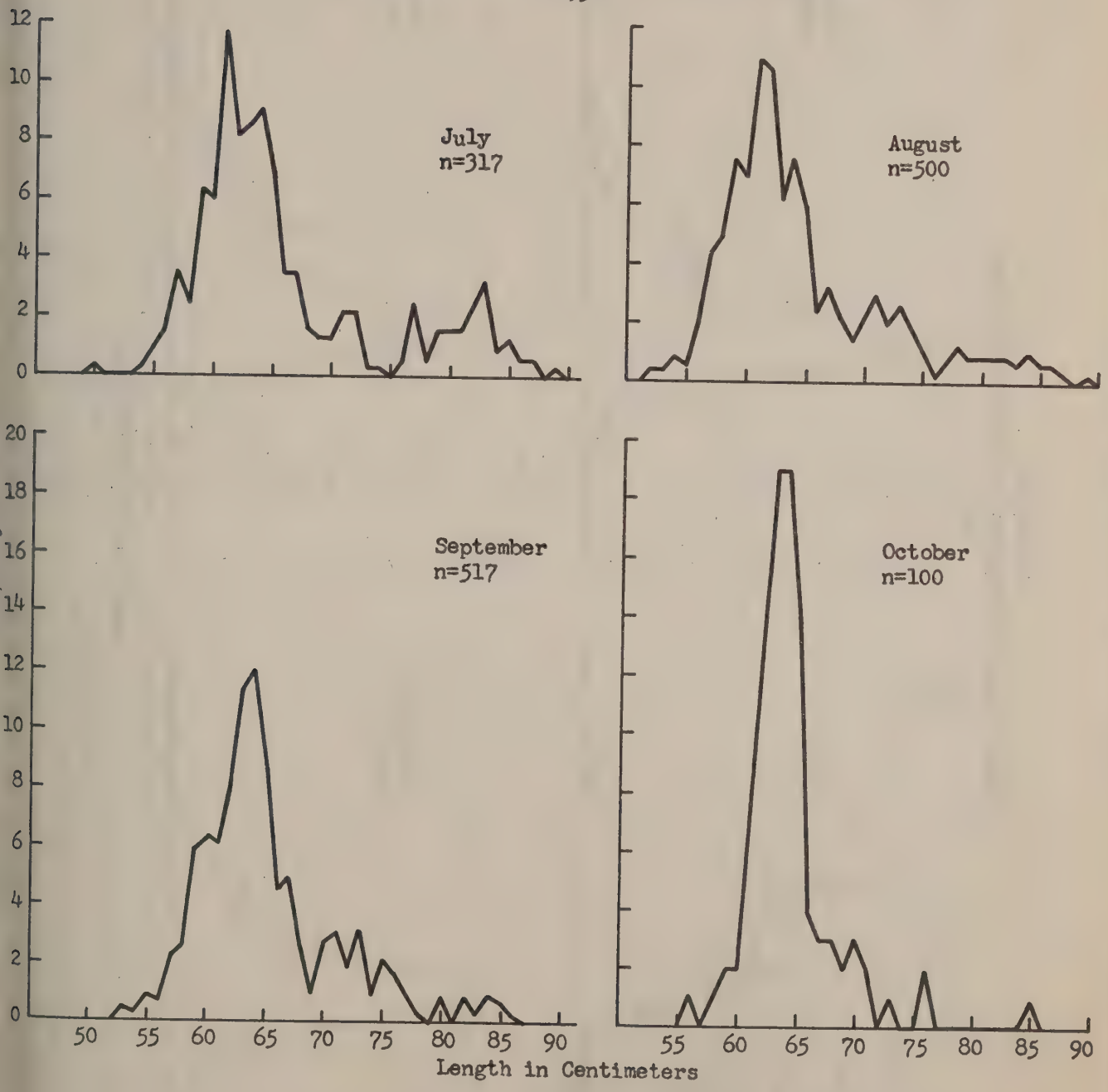


Figure 44
Albacore Length-Frequency Distribution by Month
1952

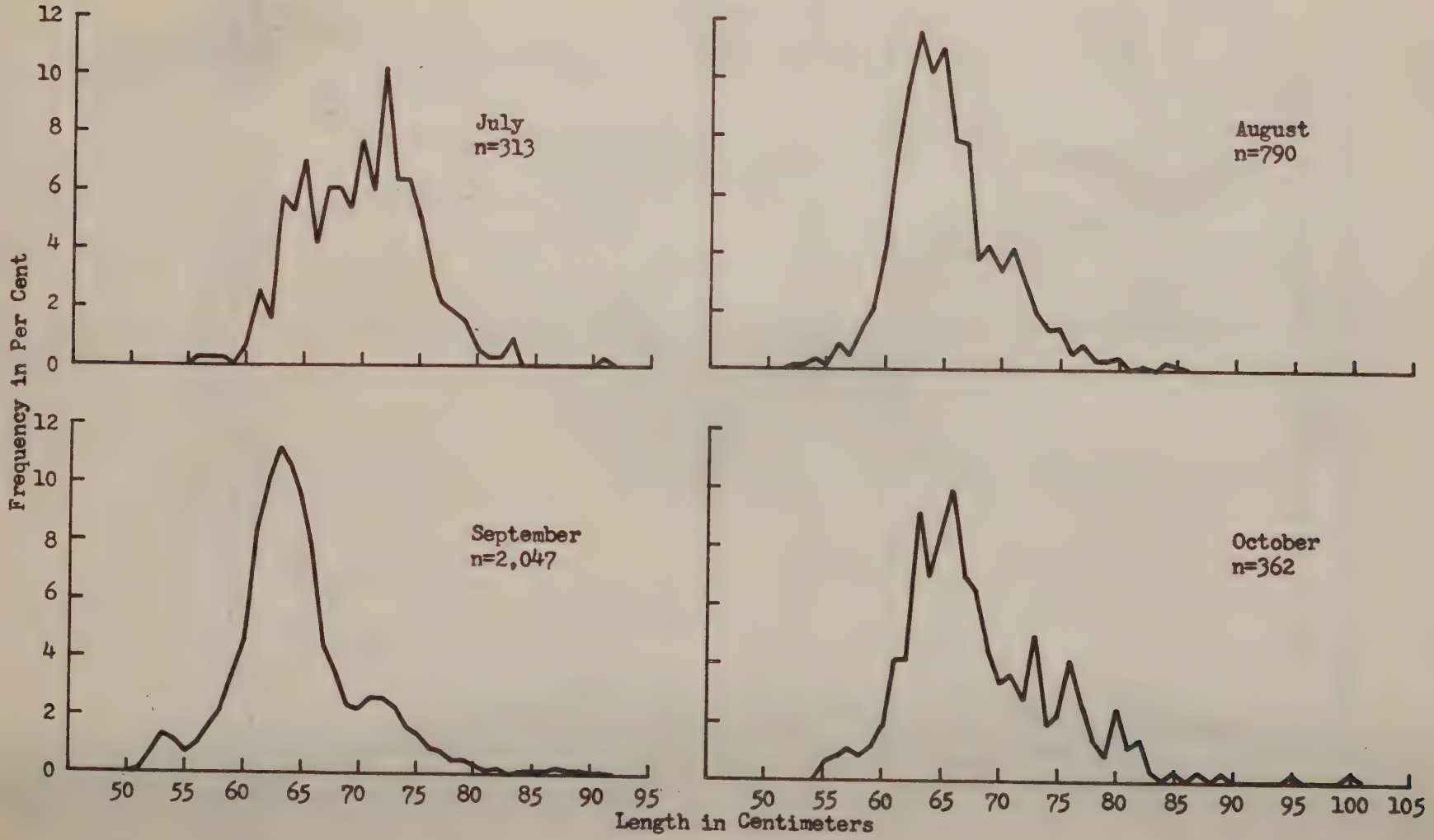


Figure 45
Albacore Length-Frequency Distribution by Month
1953

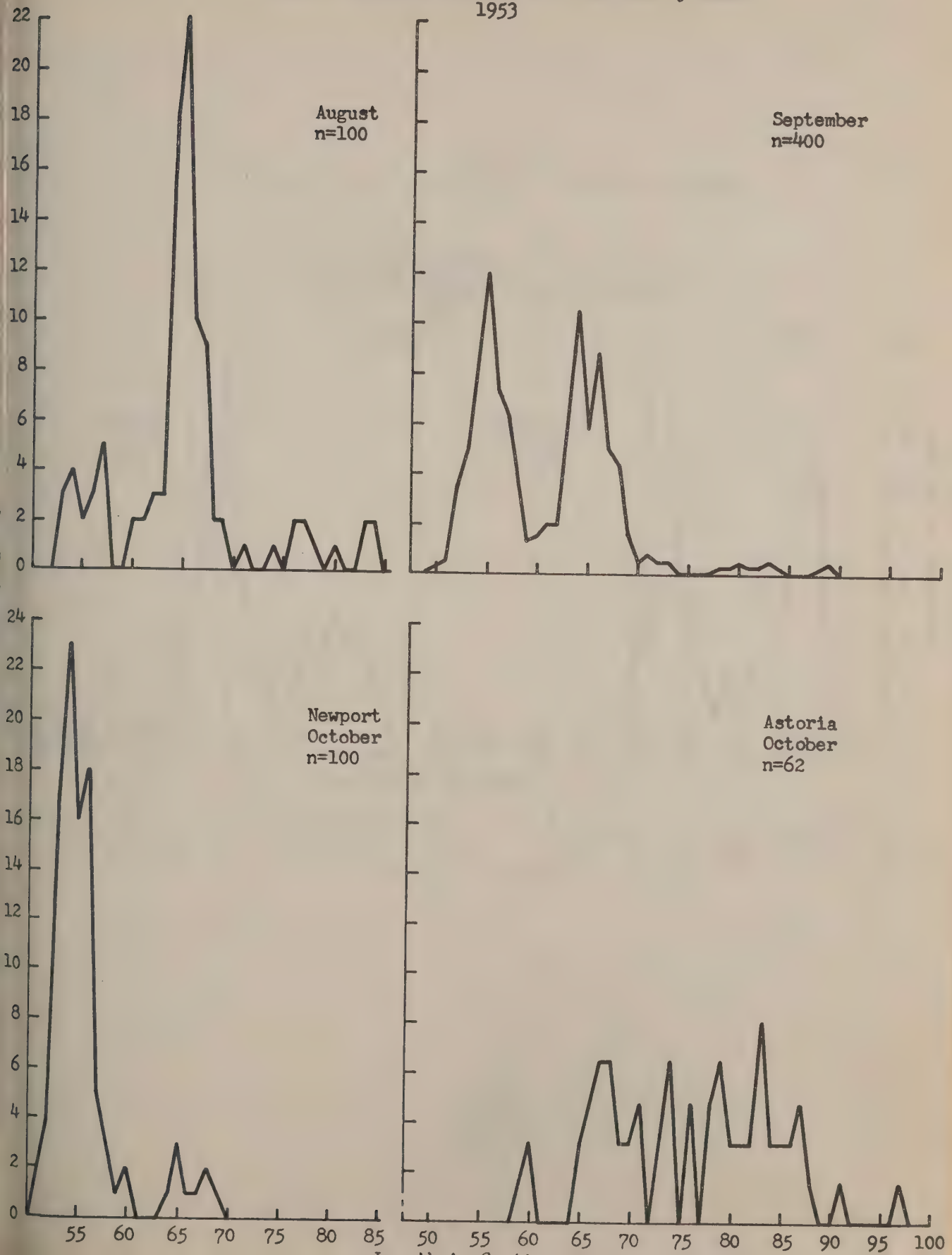


Figure 46
Albacore Length-Frequency Distribution by Month
1954

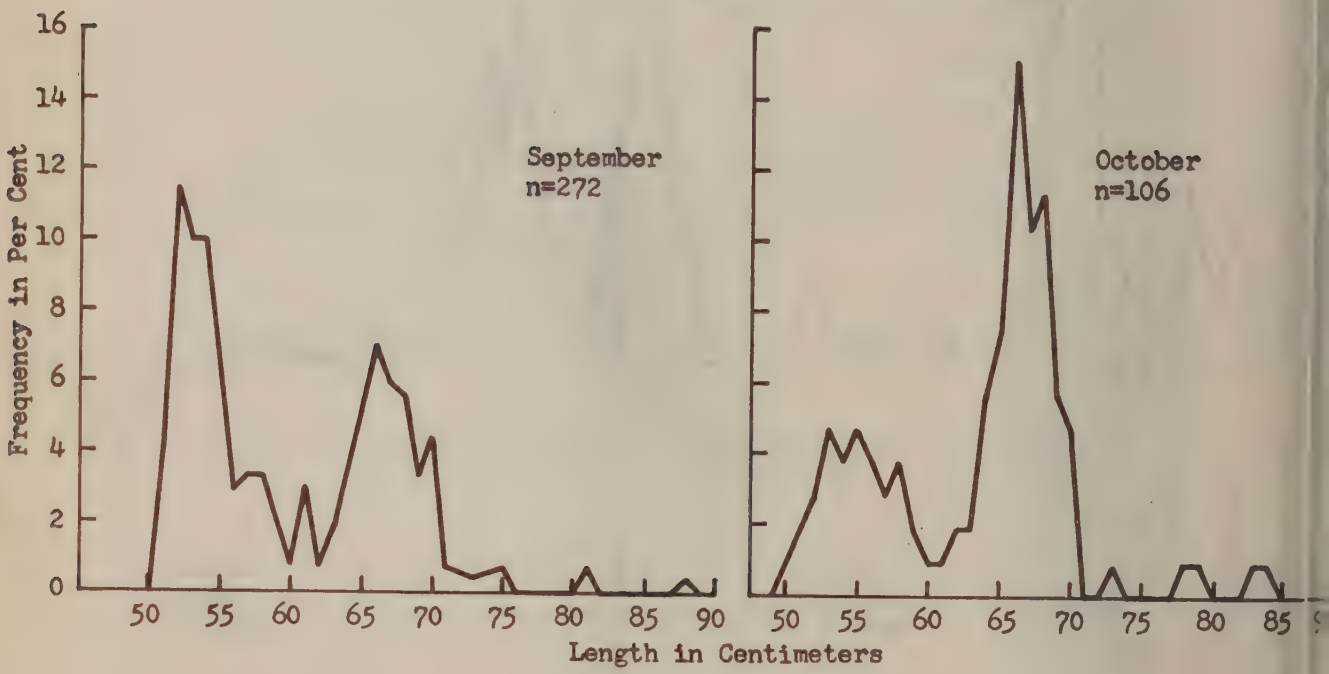


Figure 47
Albacore Length-Frequency Distribution by Month
1955

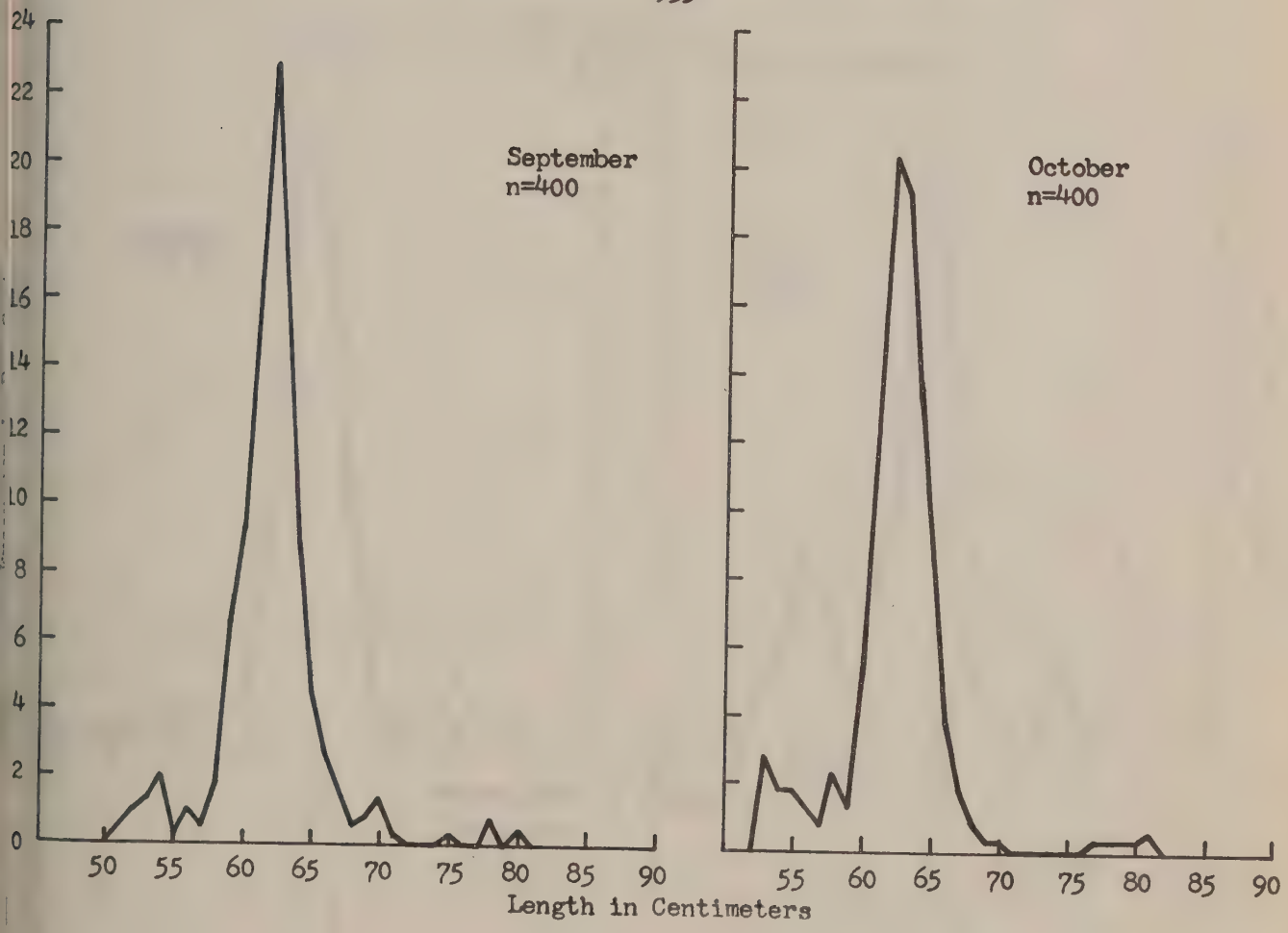


Figure 48
Albacore Length-Frequency Distribution by Month
1956

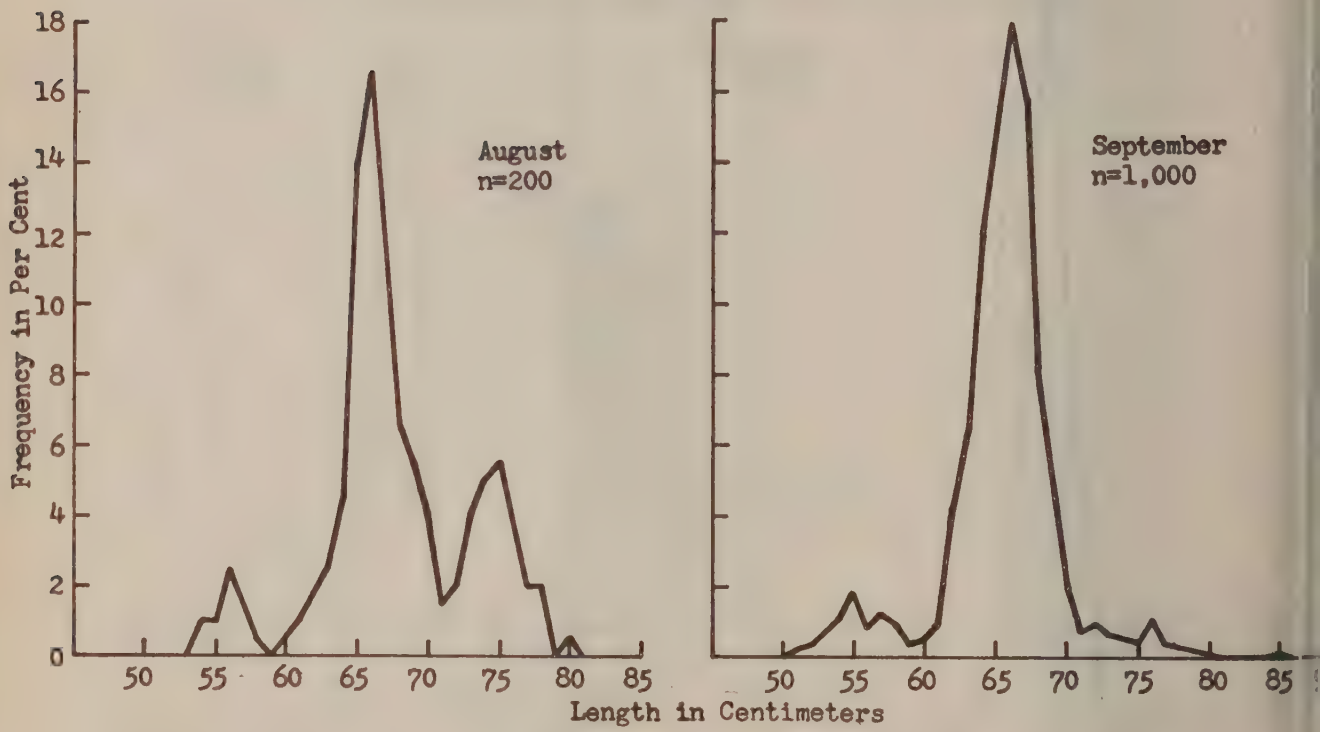


Figure 49
Albacore Length-Frequency Distribution by Month
1957

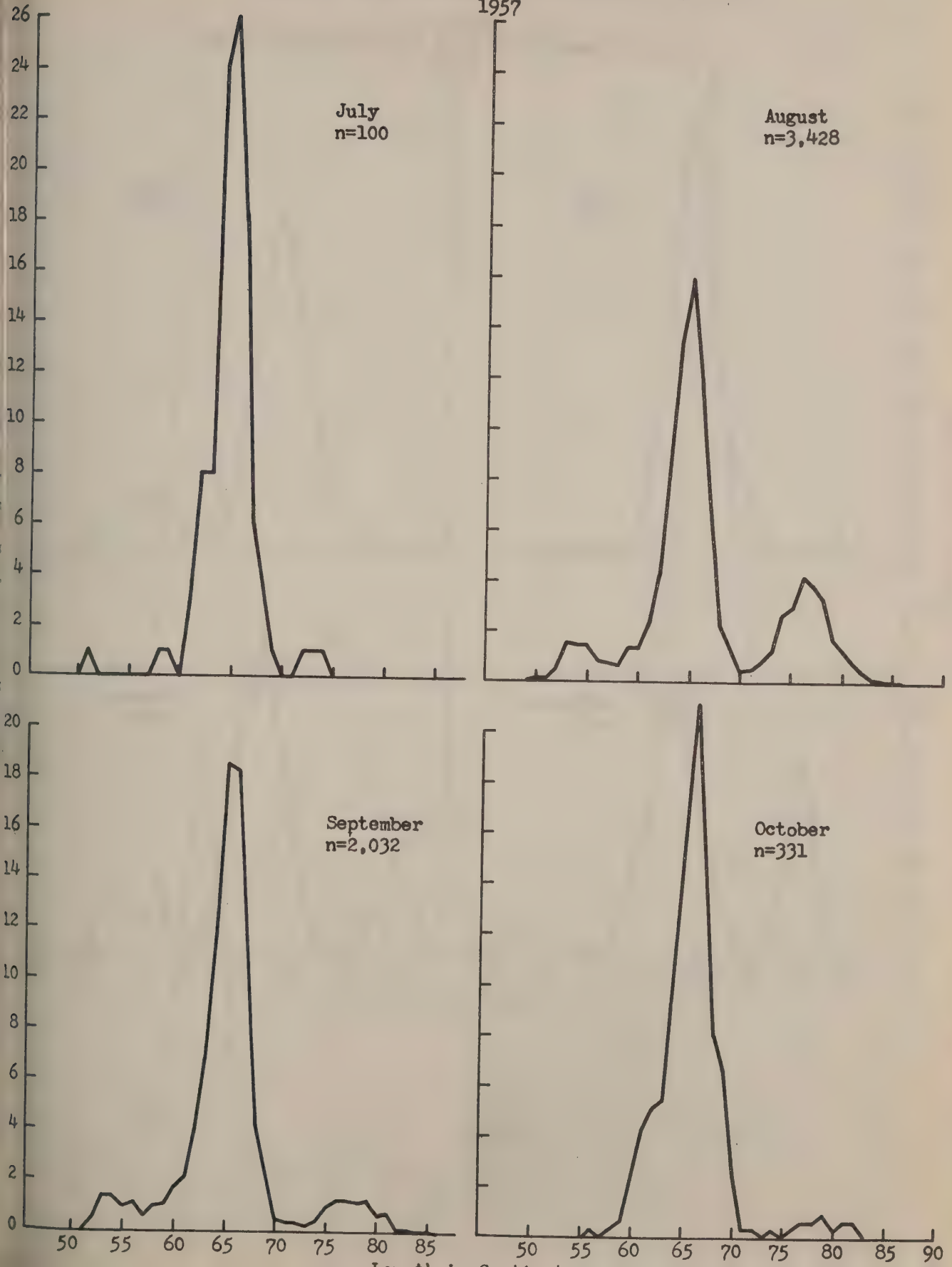


Figure 50
Albacore Length-Frequency Distribution by Month
1958

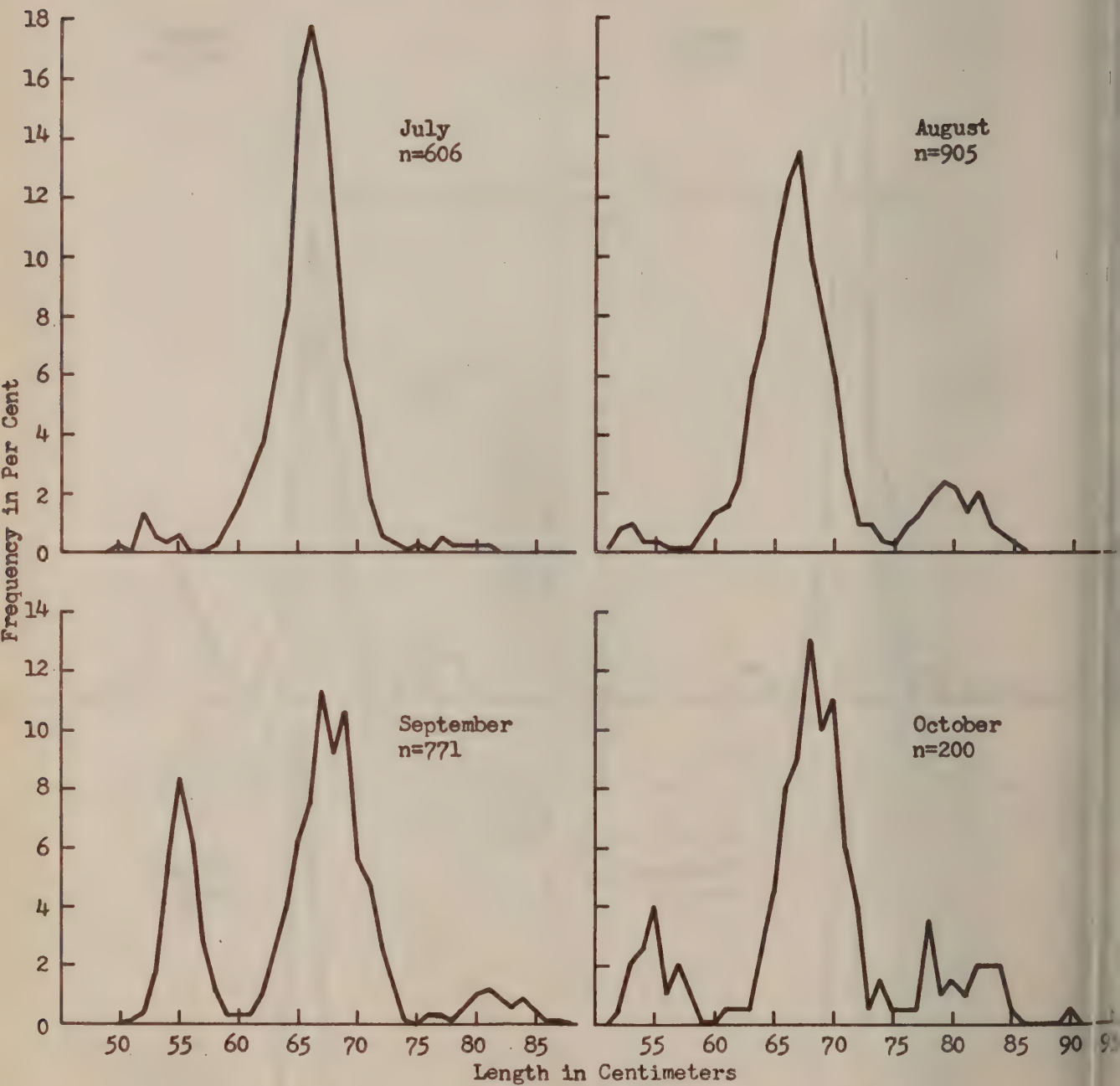


Figure 51
Albacore Length-Frequency Distribution by Month
1959

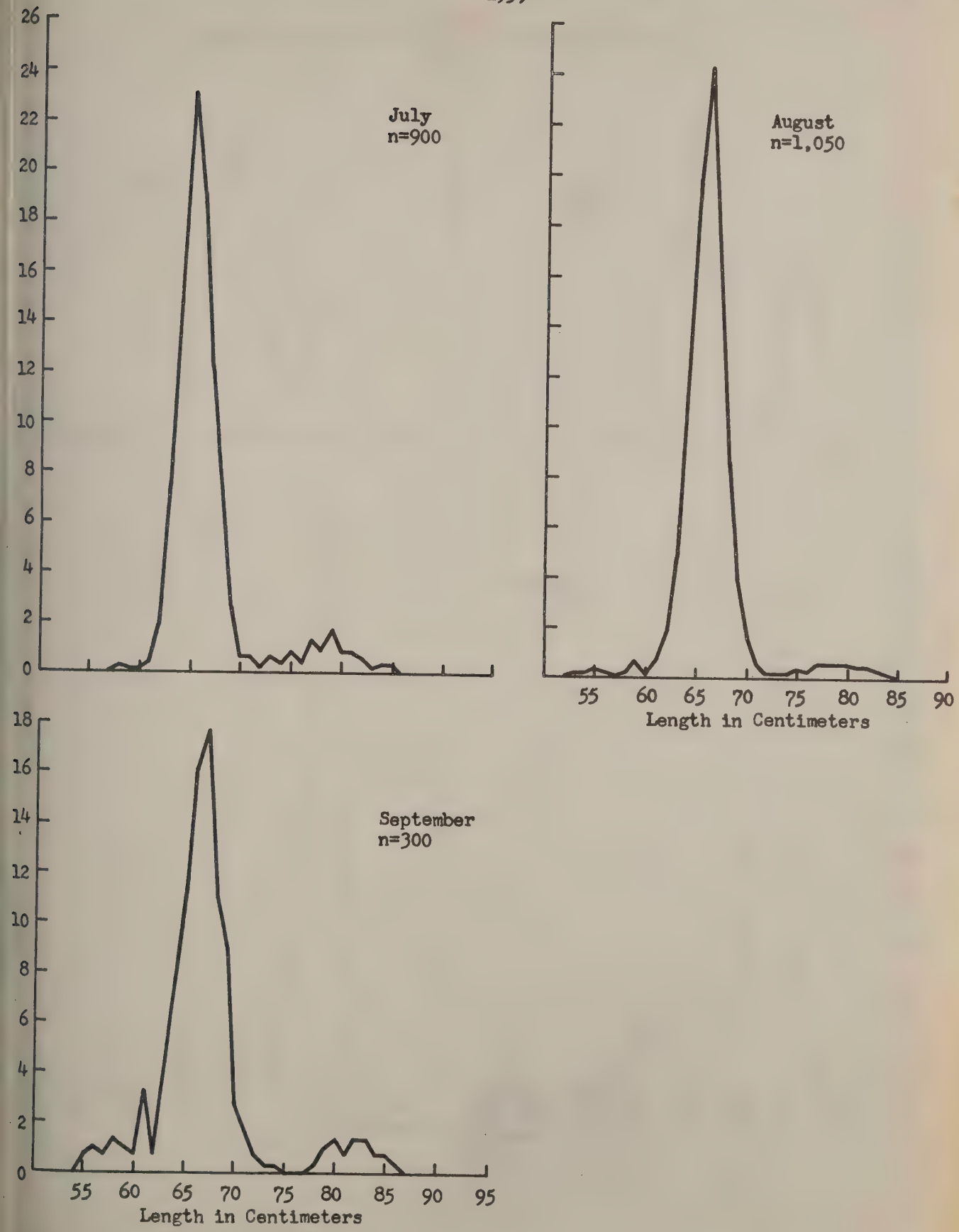
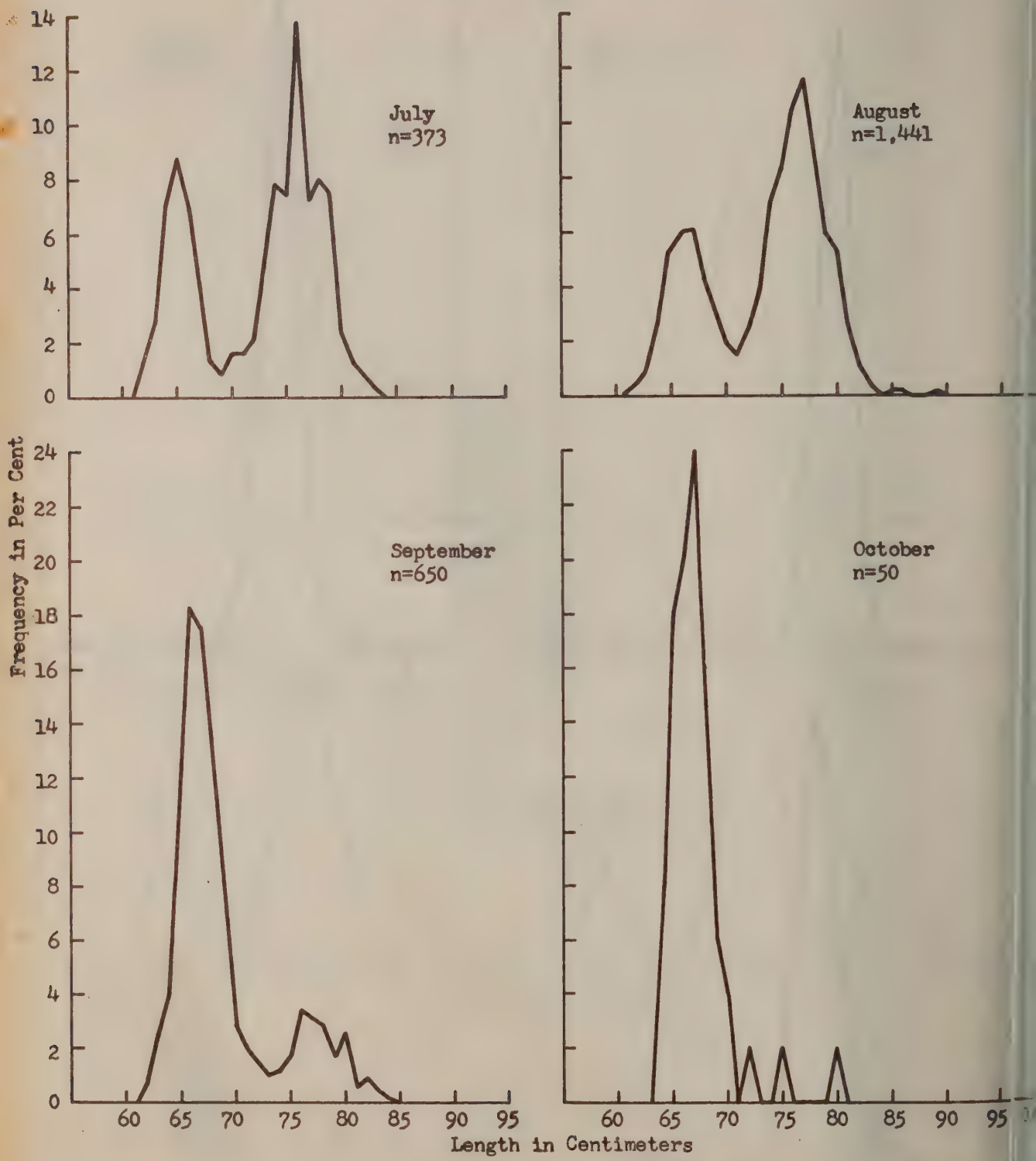


Figure 52
Albacore Length-Frequency Distribution by Month
1960



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Experience Paper No. 33

# DISTRIBUTION AND ABUNDANCE OF TUNA RELATED TO WIND AND OCEAN CONDITIONS IN THE GULF OF TEHUANTEPEC, MEXICO

By

MAURICE BLACKBURN

University of California
Scripps Institution of Oceanography
La Jolla, California, U.S.A.

## Abstract

The Gulf of Tehuantepec is exposed to northerly winds which blow consistently in winter. They cause a circulation which results in an undulating pycnocline topography; they also stir the upper part of the pycnocline in the area of its greatest elevation, where eutrophication results. It was hypothesized that yellowfin are more abundant in this area and season than in any other in the Gulf, by reason of their aggregation upon the expected high concentrations of their prey.

This hypothesis was tested by analysis of variance of logged means of yellowfin catch per day by baitboat, classified by areas, years, and seasons. It was not confirmed in its original form, but it was confirmed when the assumption of an average lag of three months between wind action and resulting crop of small nekton (yellowfin food) was made; i.e., the expected differences between areas occur in spring instead of winter. No differences were found between years, despite much variability in surface temperature over the period studied: average in 1953, low in 1954 to 1956, and high in 1957 to 1959. The same pattern of yellowfin distribution could therefore be expected from year to year in the spring months.

A similar analysis of contemporaneous skipjack data gave an entirely different result: only differences between years were significant, with catch per day highest in cool years and very low in warm years.

# DISTRIBUTION ET ABONDANCE DU THON EN FONCTION DES CONDITIONS DU VENT ET DE LA MER DANS LE GOLFE DE TEHUANTEPEC, MEXIQUE

## Résumé

Le Golfe de Tehuantepec est exposé à des vents du Nord qui soufflent assez fortement en hiver. Ils provoquent une circulation qui se traduit par une topographie condulante de la pycnocline; ils mélangent également la partie supérieure de la pycnocline dans la zone de sa plus grande élévation, avec une eutrophication en conséquence. On a supposé que les thons à nageoires jaunes seraient plus abondants dans cette zone et au cours de cette saison que partout ailleurs dans le golfe, parce qu'ils se rassembleraient autour des fortes concentrations attendues de leur proie.

Cette hypothèse a été étudiée par l'analyse de la variance des moyennes relevées des quantités de thons à nageoires jaunes capturées par jour et par bateau pêchant à l'appât vivant, classées par zones, années et saisons. L'hypothèse n'a pas été confirmée sous la forme originale, mais elle s'est trouvée vérifiée quand on a supposé qu'un délai moyen de trois mois s'écoulait entre l'action du vent et le développement résultant d'un petit nekton (nourriture du thon à nageoires jaunes); c'est-à-dire que les différences attendues entre les diverses zones se présentaient au printemps et non en hiver. On n'a pas trouvé de différence entre les années malgré la variabilité élevée de la température de surface au cours de la période de l'étude: moyenne en 1953, faible en 1954-1956 et haute en 1957-1959. On peut s'attendre en conséquence à ce que la distribution du thon à nageoires jaunes présente une allure comparable d'année en année au cours du printemps.

Une analyse identique des données parallèles concernant la bonite à ventre rayé a donné une conclusion entièrement différente: seules les différences d'une année à l'autre étaient significatives, avec des pêches journalières élevées au cours des années froides et très faibles au cours des années chaudes.

## DISTRIBUCION Y ABUNDANCIA DE ATUNES CON RELACION A LAS CONDICIONES DEL VIENTO Y EL OCEANO EN EL GOLFO DE TEHUANTEPEC, MEXICO

El Golfo de Tehuantepec está expuesto a los vientos del norte que soplan constantemente durante el invierno y causan una circulación que da por resultado una topografía picnoclina ondulante; agitan también la parte superior de la picnoclina en su área de mayor elevación, lo que da por resultado una eutroficación. Se sustentaba la hipótesis de que el atún de aleta amarilla es más abundante en esta zona y época que en cualquier otro lugar del Golfo, debido a su congregación en las esperadas concentraciones altas de sus presas.

Esta hipótesis se ensayó por análisis de las variaciones de las medias de los registros de pesca de atún de aleta amarilla por día y barco con vivero, clasificadas por zonas, años y estaciones. No se confirmó en su forma original, pero sí cuando se supuso que existía un retardo medio de tres meses entre la acción del viento y la cosecha resultante de nekton pequeño (el alimento del atún de aleta amarilla), es decir, las diferencias esperadas entre zonas ocurren en primavera en vez de en invierno. No se observaron diferencias entre los años a pesar de la mucha variación de la temperatura de la superficie en el período estudiado: normal en 1953, baja en 1954-1956 y alta en 1957-1959. Debido a ello podría esperarse la misma modalidad de atún de aleta amarilla de un año a otro en los meses de primavera.

Un análisis análogo de datos contemporáneos del barrilete dio resultados totalmente distintos; sólo tenían importancia las diferencias entre años, siendo las capturas diarias mayores en los años fríos y muy bajas en los cálidos.

## 1 INTRODUCTION

The purpose of this paper is to show how far existing knowledge of oceanic and atmospheric conditions can explain spatial and temporal differences in distribution and abundance of tuna in the Gulf of Tehuantepec, where there is a substantial fishery by United States nationals.

The published climatologic and oceanographic information is reviewed (sections 2 and 3); from this and other information it is hypothesized that certain patterns of tuna distribution occur at particular seasons of the year (section 4); data on catch per unit of fishing effort are analyzed statistically to test the hypothesis, which is confirmed in part for yellowfin tuna, Neothunnus macropterus (the principal species in the Gulf fishery), but not at all for skipjack tuna, Katsuwonus pelamis (section 5); it is shown in discussion that the hypothesis is entirely confirmed for yellowfin when amended in one reasonable particular, and that it has then some potential practical value for fishermen; for skipjack, the foundations of a different hypothesis are laid (see section 6).

The work was done at the Scripps Institution of Oceanography of the University of California, as part of the Scripps Tuna Oceanography Research (STOR) Program, with the support of the United States Bureau of Commercial Fisheries.

## 2 TOPOGRAPHIC AND CLIMATOLOGIC FEATURES OF THE REGION

The Gulf of Tehuantepec is a bight on the Pacific coast of southern Mexico, near Guatemala. It is bounded on the north by the Isthmus of Tehuantepec, which is one of the three parts of Central America that are both low and narrow; the others are in Nicaragua (lake region) and Panama (canal region). The Isthmus is about 220 km wide from north to south in its narrowest part, where the cordillera is cut by a pass some 40 km in width and 250 m in maximum elevation (Fig. 1).

Because of this topography the Gulf is exposed to weather from the Atlantic side of Central America. The same applies to the Gulfs of Papagayo and Panama, which are on the Pacific side of the other two regions of similar topography. Elsewhere along the central American isthmus, high mountains protect Pacific coastal waters from Atlantic winds.

Without this exposure, the Gulf of Tehuantepec would generally be subject to light to moderate trade winds in winter and light variable winds in summer, because of its location in relation to the seasonally fluctuating position of the Intertropical Convergence (Crowe 1952); the trade wind would probably blow from the northwest, as it does along the rest of the Pacific coast of southern Mexico (U. S. Navy Hydrographic Office 1949; Meteorological Office, London, 1956). Actually the winter wind regime is dominated by moderate to strong northerlies called Tehuantepecers, which occur through the formation of strong anticyclones over the North American plains and their extension into the Gulf of Mexico, with the winds increasing in velocity as they traverse the narrow pass on the Isthmus of Tehuantepec (U. S. Navy Hydrographic Office 1951). These conditions occur typically from October through April, when winds from the north are much more frequent than those from any of the other seven principal directions, with an average force of $> 3$ Beaufort (>10 knots); they are at peak from November through February, when northerlies are observed more frequently than winds from all other directions combined, with an average force of $>> 4$ Beaufort ($\gg$16 knots); most of the other wind in the period October through April comes from the northeast or northwest (U. S. Navy 1955, 1959).

During the remaining months of the year, May through September, the winds are more variable (mainly from the north, east, west, and directions between) and weaker (average $< 3$ Beaufort), but occasional Tehuantepecers occur (U. S. Navy 1955, 1959).

## 3 OCEANOGRAPHIC FEATURES OF THE GULF OF TEHUANTEPEC

The Gulf of Tehuantepec lies in the region of warmest surface water in the eastern Pacific, but during the winter months some of this water is at least 1 °C colder than the rest. The area of cold surface water extends up to 400 miles in a south-southwesterly direction from near the head of the Gulf (which is in the longitude of the transisthmian mountain pass), with warmer water to the east and west. Details are available in monthly average charts (U. S. Navy Hydrographic Office 1944; Meteorological Office, London, 1956).

The fact that this cooling occurs at the Tehuantepecer season, and in the part of the Gulf most likely to be disturbed by these winds, suggested a cause-and-effect relationship between

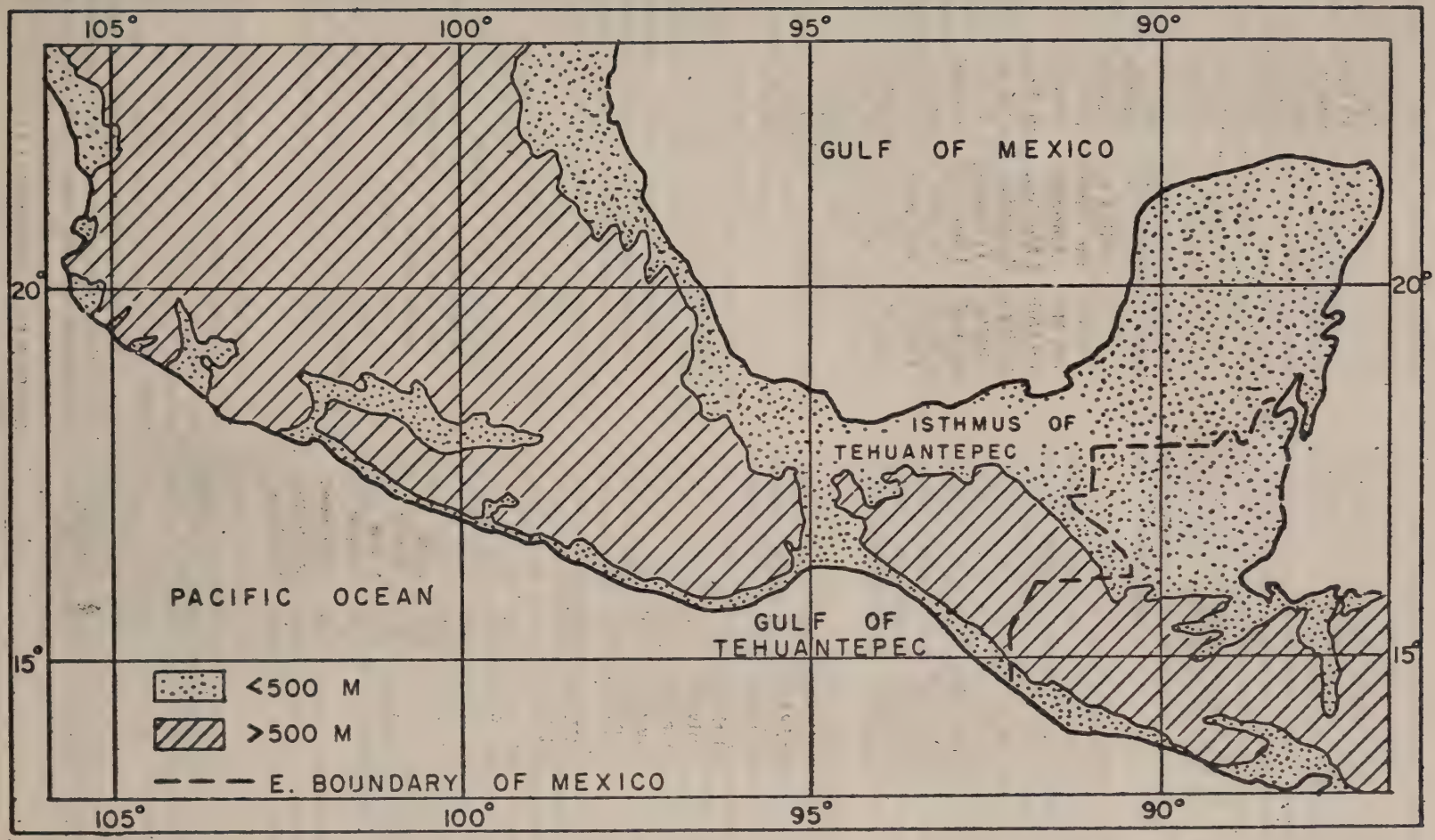


Fig. 1 Southern Mexico and adjacent regions, showing the Gulf of Tehuantepec in relation to the terrestrial topography and the Gulf of Mexico



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wind and surface temperature, involving upward movement of subsurface water. This could be expected to enrich the surface waters chemically and permit them to become more productive biologically. These ideas prompted oceanographic studies of the region by Brandhorst (1958), Roden (1961), Blackburn (1962). The summary of oceanic conditions which follows is mainly that of Blackburn: it is based on a greater number and diversity of oceanographic observations than those used by the other authors, is consistent with most of their observations and conclusions, and is believed to present the most complete description and interpretation that can be given at the present time.

Average surface current charts for June, July, and August show a simple drift along this part of the coast, west-northwest through the Gulf of Tehuantepec (Cromwell and Bennett 1959). Pycnocline topography and horizontal distributions of properties would be expected to be rather uniform zonally; this is confirmed for surface temperature by published average charts (references above; also Roden 1961, Fig. 1b), but little other useful information is available about the region in those months.

Similar charts for the Tehuantepecer months, October through April, show a different surface circulation (Cromwell and Bennett 1959). The prevailing northerly winds cause a current to flow from the head of the Gulf to the south and southwest, whereby the previously described line of flow becomes sinuous in the general form of a letter S rotated $90^{o}$ clockwise. This pattern can be transformed into the general form of a numeral 8 rotated $90^{o}$ clockwise, i.e. with a clockwise eddy in the western half of the Gulf and an anticlockwise one in the eastern half; this might be associated with changes of wind from north to northwest, with corresponding changes in the current. In either case a characteristic pycnocline topography, with a ridge or dome in the eastern loop and a hollow or trough in the western, would be expected (Fig. 2).

Such current patterns and pycnocline topographies were found on oceanographic surveys made in November 1958 and January-February 1959, and also in May 1958 and September 1959 (Blackburn 1962). Their occurrence in May and September was not expected because average charts for those months show more variable winds than in any other months, and a surface circulation pattern somewhat intermediate between that of the period June through August and the period October through April. However, the May and September findings were consistent with moderate northerlies which were blowing at the times of observation. Conversely, one of the two surveys made in November showed only slight development of the above-mentioned features, consistent with the unusually calm conditions then prevailing; in the second November survey, which was made immediately after a strong northerly, the expected features were prominent.

On the crest of the ridge the top of the pycnocline was found from about 12 to 25 m below the sea surface, and in the bottom of the hollow it occurred from about 40 to 75 m below the surface; both elevations depend upon the velocity of the northerly wind and corresponding southerly current, the difference between the elevations being greatest when the current is strongest; current velocities, measured by geomagnetic electrokinetograph, were up to 2-1/2 knots.

As the pycnocline ridge approaches the windy sea surface, the upper part of the pycnocline is stirred by the action of wind-waves. The pycnocline is weakened but does not disappear. The properties of the surface layer above it become more like those of the pycnocline itself: e.g., lower temperature, higher salinity, and higher phosphate concentration. Production of biota is stimulated in near-surface waters, with surface primary production up to 161 mg. C/m.$^{3}$/day. These phenomena are best developed in the region where the ridge top is most affected by the wind, which is along the western shoulder of the ridge (Fig. 2; see Roden 1961, Fig. 3, for distribution of wind stress). Within that meridional belt they tend to be best developed near the middle of the Gulf, over 50 miles south of the Isthmus, despite the fact that wind stress is highest at the Isthmus; this is not clearly understood, although several explanations have been suggested.

Standing crop of small zooplankton was the most frequent biological property measurement made on the cruises. It was highest in the area of the southern part of the ridge or further west in the area of the hollow. Its concentration over the ridge is interpreted as an effect of secondary production in the partly destratified eutrophic area, in succession to high primary production; in the oligotrophic area of the hollow, it is interpreted as an effect of downstream displacement and possible concentration in the western eddy. The maximum concentration was of the

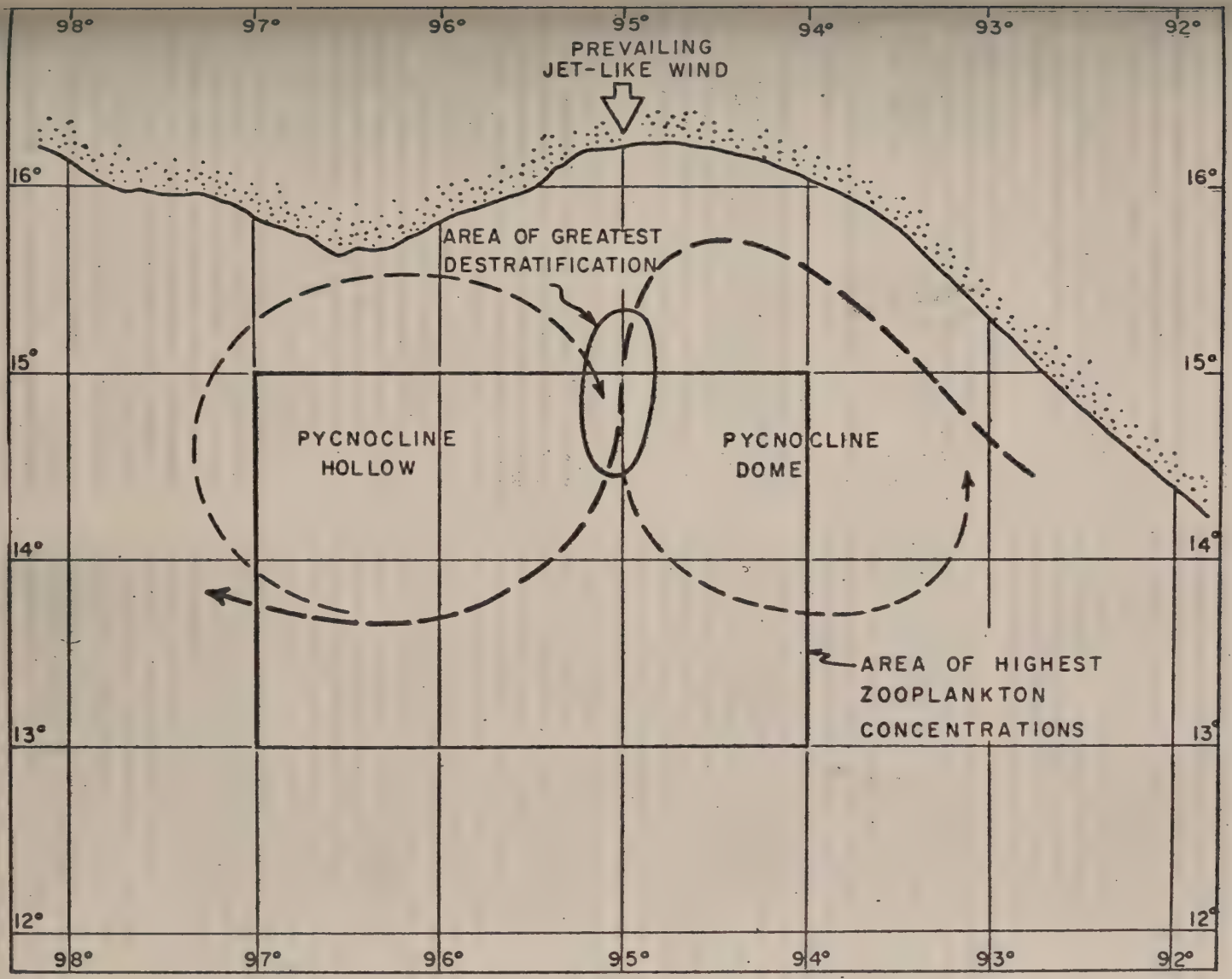


Fig. 2 Schematic chart of principal wind-connected oceanic features of the Gulf of Tehuantepec during the season of northerly winds; heavy broken line indicates the prevailing surface current pattern, lighter broken line a variation of this pattern resulting in a pair of eddies; for further explanation, see text



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rder of 100 ml/1000 $m^3$ in May and September, nd 600 ml/1000 $m^3$ in November and January.

Towards the end of the Tehuantepecer season e pycnocline topography presumably flattens, ward movement of water diminishes, and roduction and standing crops of biota decline. mmer conditions in the Gulf are probably ther uniform, as suggested above, and igotrophic.

These oceanic features and processes are dicated schematically in Fig. 2. Detailed arts and profiles of horizontal and vertical roperty distributions are available elsewhere Blackburn 1962).

## HYPOTHETICAL DISTRIBUTION OF TUNA IN THE GULF

The following considerations (a-d) were used justify a preliminary hypothesis about gross mporal and spatial variations in distribution nd abundance of yellowfin tuna in the Gulf of ehuantepec and adjacent waters, for testing ith data available from the records of the shery.

(a) Alverson (MS) has shown that yellowfin at a wide variety of species of small nekton and arge zooplankton. The possibility that yellowin aggregate when and where such food is plentiul merits consideration for the following reasons. They make extensive movements in parts of the eastern tropical Pacific; some of the movements appear to have some seasonal regularity, and hese include movements between the Gulf of Tehuantepec and the northern limit of the fishery (Schaefer et al 1961); the moving fish would require food and have good opportunities of encountering concentrations of it. Yellowfin seem to be ready to feed under most circumstances, as suggested by the presence of food in 76 percent of the large and diverse collection of stomachs examined by Alverson (MS); in the Gulf of Tehuantepec and adjacent waters, food occurred in 84 percent of stomachs. Yellowfin can be attracted to food at close range, both visually (indicated by the way they snap at odorless prey-like lures in the daytime) and chemically (Tester et al 1952, 1954, 1955).

(b) If yellowfin aggregate as suggested upon concentrations of their prey, they might also aggregate upon concentrations of small zooplankton. Small zooplankton are not a major item of yellowfin food, but they probably constitute the diet (or part of it) of most species on which yellowfin do feed, and an association between small zooplankton and yellowfin prey could be expected. The idea was suggested by the fact that standing crops of small zooplankton and small nekton, measured at the same stations in the eastern tropical Pacific in April, May and June 1958, were significantly and positively correlated; however, this was not true of similar standing crops in January and February 1959 (Blackburn and associates 1962).

(c) There are indications of statistically significant positive relationships of the kinds suggested above, i.e. between abundance of tuna and abundance of organisms in its food web, in the eastern tropical Pacific (Blackburn and associates 1962). The evidence of the relationships is not strong, but it exists for the two periods in which both kinds of information are available in the same months in the greatest numbers of 1-degree rectangles: these are April, May, and June 1958 (period of Cruise TO-58-1 of the Scripps Institution of Oceanography), and January and February 1959 (period of Cruise TO-59-1). The following measurements, of abundance of animals in or near the tuna food web, were made on the cruises; standing crops of small zooplankton, total small nekton, and four components of the small nekton (fish; cephalopods; large crustaceans; and a remainder equivalent to large zooplankton), all in displacement volume per standard volume of water strained. Attempts were made to correlate these six measurements with the commercial baitboat catch per standardized fishing day of yellowfin (both periods) and yellowfin plus skipjack (period of Cruise TO-58-1 only), in the same 1-degree rectangles and months; skipjack were caught in only a few of the rectangles in which food web organisms were sampled on Cruise TO-58-1, and in none of the rectangles so sampled on Cruise TO-49-1. Two of the 18 correlation coefficients were significant at the 5 percent level of probability, both positive in sign: yellowfin plus skipjack (mostly yellowfin) with large crustacea on TO-58-1, and yellowfin with small zooplankton on TO-59-1. The numbers of degrees of freedom in the tests ranged from 18 to 31.

(d) It was shown in section 3 that the highest concentrations of small zooplankton all occurred in a particular area. If these observations have been validly interpreted as effects of oceanic phenomena regularly resulting from Tehuantepecers, similar distributions of small

zooplankton should occur over most of the Tehuantepecer season (October through April); and occasionally in May and September at a lower level of abundance; and perhaps occasionally in June, July and August, although a uniform distribution of sparse zooplankton throughout the Gulf is more to be expected at that season. The area in which the highest concentrations of small zooplankton are expected is between 13° and 15° N latitude and 94° and 97°W longitude: this includes all previously observed locations of such concentrations and parts of the pycnocline topography thought to be associated with them (Blackburn 1962).

It was therefore hypothesized that yellowfin tuna are characteristically distributed in the Gulf of Tehuantepec in the way that small zooplankton are: most abundantly in the Tehuantepecer season from October through April, and then in the area between 13° and 15°N, 94° and 97°W; least abundantly, and uniformly over the region, in the calm season from June through August; and in an intermediate way in May and September.

This hypothesis was seen to have possible weaknesses, especially in the argument from a few observed zooplankton distributions to a general one (d above) and thence to a similar contemporaneous distribution of tuna prey (b above). It was the best one that could logically be advanced for testing, however, and it was thought that testing might lead to its improvement. It is tested in section 5 and discussed in section 6.

Little information exists to justify the application of this or any similar hypothesis to skipjack tuna. A cursory examination of fishery records showed that the distribution of skipjack is very different from that of yellowfin, and that the above-mentioned hypothesis could not possibly apply to skipjack. The differences between the distributions of the two species are shown and discussed in sections 5 and 6.

## 5 ACTUAL DISTRIBUTION AND ABUNDANCE OF TUNA IN THE GULF

### 5.1 Yellowfin

The Inter-American Tropical Tuna Commission collects data on catch in tons of each species of tuna and on numbers of fishing days, for the bait-boat and purse-seine fisheries separately, by 1-degree rectangles and months. The Commission and the United States Bureau of Commercial Fisheries co-operate in preparing tabulations of catch, numbers of days, and mean catch per standardized fishing day. The catch per standardized fishing day, explained by Shimada and Schaefer (1956), is considered to be the best available measurement of average apparent abundance of yellowfin or skipjack. The data analyzed in this paper, for both yellowfin and skipjack, were taken from an unpublished tabulation supplied by the Bureau in December 1961: they were checked as far as possible with the original records of the Commission, and the discrepancies noted were all trivial for the purpose of this paper. Only bait-boat fishery records were used: the purse-seine fishery in the Gulf of Tehuantepec was small until about 1959.

Fig. 3 shows the 1-degree rectangles in the region, which were grouped for the purpose of this paper into eight 2-degree rectangles A, B, ...H. Rectangles C, D, and E are those in which tuna would be expected to be most abundant during the Tehuantepecer season, according to the hypothesis developed above. The odd 1-degree rectangle is designated 0; it is an area on the continental shelf in which few tuna of either species are caught.

Table I shows the total catch and number of fishing days for yellowfin over the period March 1951, through February 1960, dissected by months and areas (O, A, B, ...H). The catch and day entries were obtained by adding those for the 1-degree rectangles. Similar information for the earlier part of 1951 and the later part of 1960 was not used: in the former period the data-gathering system, which began in January 1951, was probably less efficient than it became later; in the latter period the bait-boat fishery was small in size.

Table I also shows the mean catch per day for each month for the combined areas. This index is highest in March, April, and May, a period which is broadly identifiable with the later part of the Tehuantepecer season; so for further grouping of the data of Table I it is convenient to use the four quarter-years March-May, June-August, etc. Table II presents the data of Table I in that way, with catch per day for each period and area; it also gives catch, days, and catch per day for each area for the whole year.

The period December-February is broadly identifiable with the peak of Tehuantepecer activity, which declines in the period March-May;

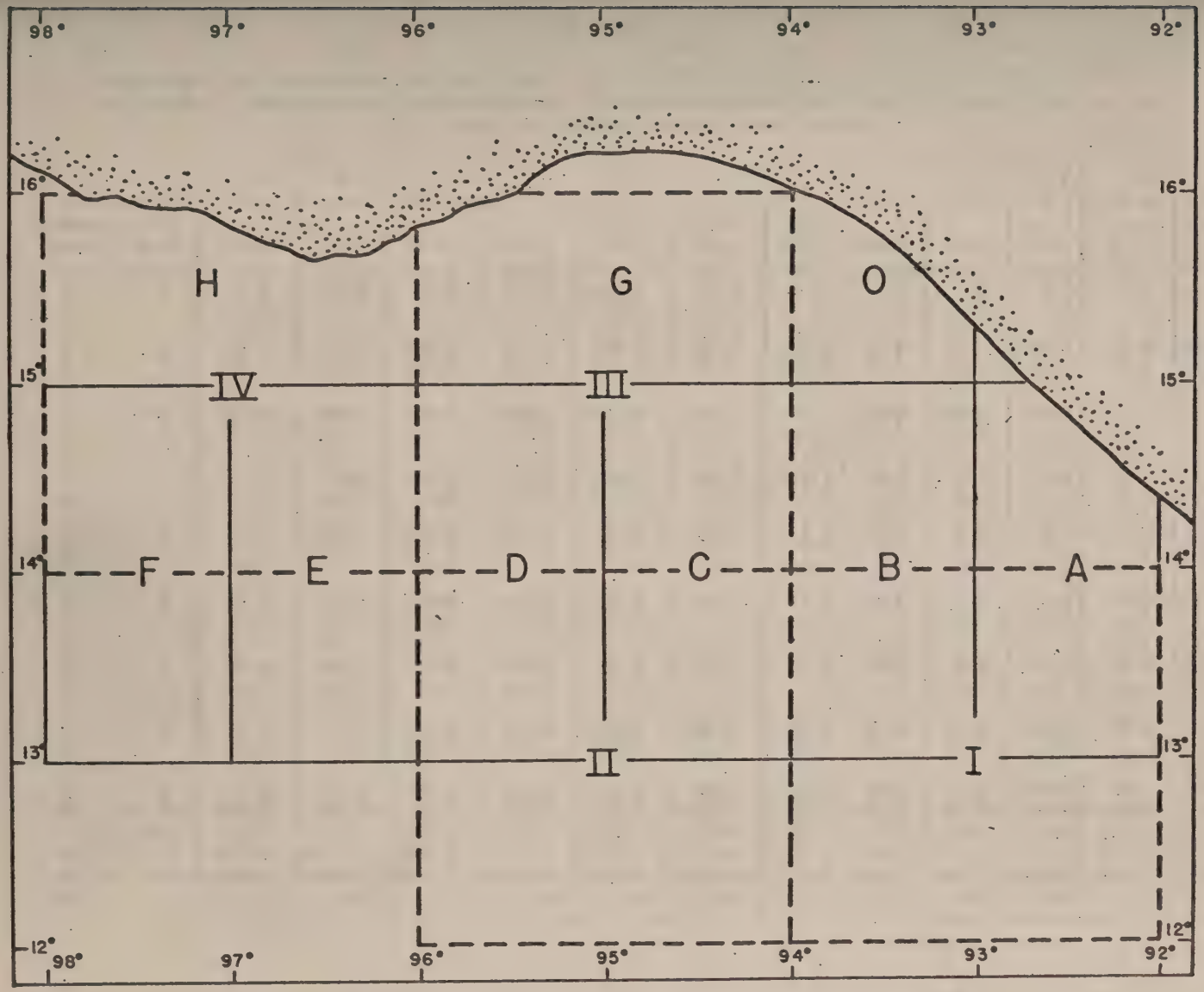


Fig. 3 Gulf of Tehuantepec and adjacent waters, showing areas A-H ($2^{o} \times 1^{o}$), and area 0 ($1^{o} \times 1^{o}$) referred to in Tables I to XI, and areas I to IV ($2^{o} \times 2^{o}$) referred to in Figs. 4 and 5

Table I

Yellowfin in the Tehuantepec baitboat fishery, March 1951-February 1960; number of tons caught (T), and number of standardized fishing days (D), by areas shown in Fig. 3, and by months; tons per day (T/D) shown for combined areas in each month.

| Measure-ment | Area | Jan. | Feb. | March | April | May | June | July | August | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | O | 1.5 | 17.7 | 13.2 | 18.0 | 42.5 | 26.0 | 1.0 | 4.0 | 5.0 | 3.9 | 0.0 | 1.1 |
| D | | 7.0 | 24.7 | 20.6 | 26.3 | 25.8 | 12.7 | 5.5 | 2.6 | 2.8 | 7.5 | 4.1 | 5.0 |
| T | A | 590.3 | 401.7 | 485.0 | 576.2 | 326.0 | 164.3 | 407.6 | 93.2 | 67.7 | 58.0 | 33.7 | 165.1 |
| D | | 88.0 | 133.8 | 167.8 | 142.6 | 111.2 | 65.0 | 130.9 | 47.1 | 26.1 | 48.8 | 19.1 | 42.3 |
| T | B | 384.0 | 858.1 | 307.6 | 1215.0 | 822.6 | 660.7 | 71.1 | 53.9 | 140.6 | 185.8 | 355.5 | 18.1 |
| D | | 68.8 | 184.9 | 123.5 | 197.4 | 182.4 | 156.8 | 38.1 | 27.2 | 47.3 | 72.1 | 57.8 | 14.7 |
| T | C | 8.4 | 67.4 | 463.4 | 767.3 | 1714.9 | 46.7 | 2.5 | 4.8 | 23.5 | 8.0 | 2.0 | 69.6 |
| D | | 5.4 | 27.0 | 75.8 | 107.3 | 207.3 | 25.8 | 4.2 | 7.8 | 6.4 | 5.3 | 5.1 | 9.8 |
| T | D | 12.2 | 618.1 | 1339.8 | 1412.2 | 780.8 | 21.2 | 2.5 | 1.5 | 2.0 | 2.0 | 3.0 | 0.0 |
| D | | 4.5 | 54.7 | 141.2 | 104.8 | 126.6 | 13.4 | 1.5 | 4.7 | 1.0 | 2.0 | 2.8 | 0.6 |
| T | E | 77.4 | 1162.0 | 1092.5 | 1484.3 | 209.2 | 16.2 | 15.5 | 0.9 | 1.5 | 20.5 | 27.0 | 65.5 |
| D | | 29.5 | 130.3 | 169.9 | 194.8 | 65.4 | 10.7 | 6.1 | 4.3 | 1.0 | 9.4 | 6.8 | 7.6 |
| T | F | 271.4 | 426.3 | 149.0 | 1422.7 | 167.6 | 70.5 | 0.0 | 2.0 | 2.0 | 2.5 | 9.2 | 228.7 |
| D | | 64.5 | 105.7 | 56.0 | 220.2 | 50.3 | 11.9 | 0.5 | 2.2 | 1.2 | 4.1 | 7.4 | 22.0 |
| T | G | 40.9 | 131.0 | 435.5 | 395.9 | 1437.7 | 131.0 | 87.7 | 30.6 | 59.2 | 5.0 | 26.4 | 11.7 |
| D | | 30.7 | 73.0 | 123.5 | 137.4 | 224.6 | 52.5 | 27.8 | 31.1 | 20.7 | 12.7 | 21.5 | 15.5 |
| T | H | 337.8 | 257.7 | 1597.5 | 535.5 | 950.8 | 103.8 | 162.7 | 44.0 | 53.9 | 102.0 | 18.1 | 76.7 |
| D | | 118.2 | 157.3 | 320.8 | 177.0 | 230.2 | 60.4 | 42.3 | 26.0 | 21.8 | 30.6 | 24.2 | 33.6 |
| T | Total | 1723.9 | 3940.0 | 5883.5 | 7827.1 | 6451.5 | 1240.4 | 750.6 | 234.9 | 355.4 | 387.7 | 474.9 | 636.5 |
| D | | 416.6 | 891.4 | 1199.1 | 1307.8 | 1223.8 | 409.2 | 256.9 | 153.0 | 128.3 | 192.5 | 148.8 | 151.1 |
| T/D | | 4.14 | 4.42 | 4.91 | 5.98 | 5.27 | 3.03 | 2.92 | 1.54 | 2.77 | 2.01 | 3.19 | 4.21 |

Table II

Data of Table I (yellowfin) grouped by three-month periods

| Measure-ment | Area | Dec-Feb. | Mar.-May | June-Aug. | Sept.-Nov. | Total |
|---|---|---|---|---|---|---|
| T | O | 20.3 | 73.7 | 31.0 | 8.9 | 133.9 |
| D | | 36.7 | 72.7 | 20.8 | 14.4 | 144.6 |
| T/D | | 0.55 | 1.01 | 1.49 | 0.62 | 0.93 |
| T | A | 1157.1 | 1387.2 | 665.1 | 159.4 | 3368.8 |
| D | | 264.1 | 421.6 | 243.0 | 94.0 | 1022.7 |
| T/D | | 4.38 | 3.29 | 2.74 | 1.70 | 3.29 |
| T | B | 1260.2 | 2344.6 | 785.7 | 681.9 | 5072.4 |
| D | | 268.4 | 503.3 | 222.1 | 177.2 | 1171.0 |
| T/D | | 4.70 | 4.66 | 3.54 | 3.85 | 4.33 |
| T | C | 145.4 | 2945.6 | 54.0 | 33.5 | 3178.5 |
| D | | 42.2 | 390.4 | 37.8 | 16.8 | 487.2 |
| T/D | | 3.45 | 7.55 | 1.43 | 1.99 | 6.52 |
| T | D | 630.3 | 3532.8 | 25.2 | 7.0 | 4195.3 |
| D | | 59.8 | 372.6 | 19.6 | 5.8 | 457.8 |
| T/D | | 10.54 | 9.48 | 1.29 | 1.21 | 9.16 |
| T | E | 1304.9 | 2786.0 | 32.6 | 49.0 | 4172.5 |
| D | | 167.4 | 430.1 | 21.1 | 17.2 | 635.8 |
| T/D | | 7.80 | 6.48 | 1.55 | 2.85 | 6.56 |
| T | F | 926.4 | 1739.3 | 72.5 | 13.7 | 2751.9 |
| D | | 192.2 | 326.5 | 14.6 | 12.7 | 546.0 |
| T/D | | 4.82 | 5.33 | 4.97 | 1.08 | 5.04 |
| T | G | 183.6 | 2269.1 | 249.3 | 90.6 | 2792.6 |
| D | | 119.2 | 485.5 | 111.4 | 54.9 | 771.0 |
| T/D | | 1.54 | 4.67 | 2.24 | 1.65 | 3.62 |
| T | H | 672.2 | 3083.8 | 310.5 | 174.0 | 4240.5 |
| D | | 309.1 | 728.0 | 128.7 | 76.6 | 1242.4 |
| T/D | | 2.17 | 4.24 | 2.41 | 2.27 | 3.41 |
| T | Total | 6300.4 | 20162.1 | 2225.9 | 1218.0 | 29906.4 |
| D | | 1459.1 | 3730.7 | 819.1 | 469.6 | 6478.5 |
| T/D | | 4.32 | 5.40 | 2.72 | 2.59 | 4.62 |

the period September-November includes the beginning of the activity. It might therefore be expected that catch per day would be highest in December-February and lowest in June-August. In fact the maximum for the combined areas occurs in March-May and the minimum in September-November (Table II). Catch per day is highest for the year in December-February or March-May for all areas except 0; it is lowest for the year in one of the other two periods for all areas except G, H, and O. These remarks apply particularly to areas C, D, and E, where catch per day shows the greatest seasonal range (>6 tons in three-monthly means); the smallest seasonal range (<1 ton) occurs in area 0. Areas C, D, and E have also the highest catch per day for all seasons combined, and 0 has the lowest. Means for different areas have a greater range in December-February (>9 tons; highest in D and E, lowest in 0) than in any other quarter-year, the smallest range occurring in September-November (<4 tons; highest in B, lowest in 0). These results agree fairly well with the hypothesis as far as the suggested best areas for yellowfin are concerned, but the suggested best and worst seasons for yellowfin seem to occur about three months later than expected; this is discussed below.

A more rigorous examination of the data was attempted by analysis of variance of catch per day means by areas, seasons, and years. It was decided, from experience in handling the data, that no mean should be based on <5 days and that the base should be >10 days whenever possible; as a result the data prior to March 1953 were excluded, those subsequent to February 1957 were with difficulty included, and only two seasons were recognized (March-May, with 58 percent of all fishing days; and the rest of the year). Area 0 was ignored. The means were multiplied by 100, raised by 1.00 and logged. Table III gives the data used in the analyses of variance; each entry for the period June-February is assigned to the earlier of the two calendar years in which the period falls.

Table IV gives the results of three analyses, (i), (ii) and (iii), made in the manner of Snedecor (1946, p. 304 et seq.): area, season, and year are considered as fixed effects and second order interaction is taken as the estimate of experimental error. Analysis (i) is for the five years 1953 to 1957 with the above-mentioned eight areas and two seasons; three of the 80 catch per day means were based on <10>5 days. Analyses (ii) and (iii) represent different attempts to utilize the data of 1958 and 1959, when fishing effort was much lower than in the previous years, without introducing too many low-based means; special interest attaches to these years because most of the oceanographic work was done then. In (ii), 1958 and 1959 were regarded as a single year (making six), with eight areas and two seasons as before; six of the 96 means were based on <10>5 days. In (iii), 1958 and 1959 were considered separately (giving a total of seven years), but four areas of low fishing effort (C, D, E, F) were regarded as a single area (hence five areas in all): two seasons were recognized as before; one of the 70 means was based on <10 = 5 (actually 4.9) days.

It was expected from Tables II and III that the season effect would be significant: it was included in the analyses mainly to obtain enough degrees of freedom to test the first-order interactions, none of which are significant. Actually the season effect, although large, is not significant in analysis (iii); it is significant in (i) and (ii). The year effect is not significant at all. The area effect is almost significant in analysis (iii), where F for areas = 4.16 (cf. F = 4.22 for significance at P = 0.05); it is fairly large although not significant in (i) and (ii) and the same is true of the area-season interactions.

In view of these observations and the hypothesis under consideration, it was decided to analyze the data of (i) and (ii) further for the separate seasons; i.e., with areas and years as main effects (Snedecor 1946, p. 253 et seq.). The results are given in Table V: neither effect is significant in June-February; the area effect is highly significant in March-May although the year effect is not significant. For the combined years the highest logged means in the March-May analyses are for areas D, C and E, in that order. It is shown by the D test (Snedecor 1956, p. 251-253) that the mean for area D differs significantly from those of areas A, F, G, and possibly H; the mean for area C differs significantly from those of areas A and G, however the mean for area E is not significantly different from any other: this statement applies to both (i) and (iii) in Table V. In the data of Table IV (iii), the combined areas C, D, E and F have a higher logged mean in March-May than the means for the individual areas A, B, G and H, although none of the differences is quite significant.

**Table III**

**Yellowfin in the Tehuantepec baitboat fishery, March 1953-February 1960; number of tons caught (T), number of standardized fishing days (D), and log ((100. T/D) + 1), by areas, years and seasons**

| Measure-ment | Area | 1953 | | 1954 | | 1955 | | 1956 | | 1957 | | 1958 | | 1959 | | 1958 + 1959 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. |
| T | A | 45.9 | 9.5 | 44.6 | 668.6 | 407.4 | 111.0 | 146.0 | 493.5 | 525.6 | 49.4 | 26.0 | 75.5 | 162.5 | 39.7 | 188.5 | 115.2 |
| D | | 28.8 | 28.0 | 43.9 | 113.9 | 75.1 | 45.1 | 60.5 | 129.4 | 127.3 | 39.0 | 20.5 | 33.3 | 38.0 | 22.6 | 58.5 | 55.9 |
| log | | 2.2061 | 1.5441 | 2.0128 | 2.7694 | 2.7348 | 2.3927 | 2.3838 | 2.5821 | 2.6170 | 2.1072 | 2.1072 | 2.3579 | 2.6325 | 2.2480 | 2.5092 | 2.3160 |
| T | B | 246.0 | 48.4 | 130.1 | 439.3 | 852.8 | 145.9 | 74.9 | 1031.6 | 507.4 | 202.2 | 23.7 | 375.4 | 87.5 | 351.4 | 111.2 | 726.8 |
| D | | 66.1 | 38.6 | 51.1 | 116.2 | 111.1 | 30.2 | 37.5 | 246.7 | 111.0 | 51.5 | 16.2 | 62.6 | 36.1 | 51.2 | 52.3 | 113.8 |
| log | | 2.5717 | 2.1004 | 2.4082 | 2.5786 | 2.8859 | 2.6848 | 2.3032 | 2.6222 | 2.6609 | 2.5955 | 2.1673 | 2.7789 | 2.3856 | 2.8370 | 2.3304 | 2.8062 |
| T | C | 221.4 | 100.8 | 692.2 | 4.7 | 580.8 | 6.5 | 320.5 | 53.0 | 839.8 | 34.0 | 40.5 | 21.0 | 78.4 | 0.0 | 118.9 | 21.0 |
| D | | 37.3 | 20.5 | 89.5 | 11.0 | 64.5 | 10.0 | 28.9 | 25.2 | 104.0 | 14.1 | 14.2 | 4.7 | 21.0 | 1.0 | 35.2 | 5.7 |
| log | | 2.7745 | 2.6928 | 2.8887 | 1.6435 | 2.9547 | 1.8195 | 3.0453 | 2.3243 | 2.9070 | 2.3838 | 2.4564 | 2.6513 | 2.5729 | 0.0000 | 2.5302 | 2.5670 |
| T | D | 1081.2 | 7.5 | 456.8 | 26.7 | 405.1 | 523.1 | 1198.1 | 12.2 | 296.7 | 6.0 | 0.0 | 78.5 | 73.4 | 7.0 | 73.4 | 85.5 |
| D | | 86.7 | 6.7 | 68.9 | 10.5 | 29.0 | 44.5 | 118.5 | 6.6 | 43.7 | 5.7 | 1.5 | 7.2 | 16.3 | 1.3 | 17.8 | 8.5 |
| log | | 3.0962 | 2.0531 | 2.8222 | 2.4065 | 3.1456 | 3.0708 | 3.0051 | 2.2695 | 2.8325 | 2.0253 | 0.0000 | 3.0378 | 2.6542 | 2.7316 | 2.6160 | 3.0029 |
| T | E | 1138.6 | 48.2 | 228.1 | 54.2 | 201.1 | 1084.7 | 923.6 | 110.0 | 123.3 | 68.5 | 1.5 | 11.2 | 47.0 | 0.0 | 48.5 | 11.2 |
| D | | 121.0 | 16.6 | 51.9 | 11.3 | 48.4 | 102.3 | 126.1 | 37.4 | 34.3 | 20.3 | 2.6 | 13.7 | 16.0 | 1.0 | 18.6 | 14.7 |
| log | | 2.9741 | 2.4639 | 2.6435 | 2.6821 | 2.6191 | 3.0257 | 2.8651 | 2.4698 | 2.5563 | 2.5289 | 1.7709 | 1.9191 | 2.4698 | 0.0000 | 2.4183 | 1.8865 |
| T | F | 1186.1 | 138.9 | 155.1 | 150.7 | 95.5 | 206.8 | 52.9 | 322.0 | 29.9 | 183.6 | 2.0 | 9.4 | 9.5 | 0.5 | 11.5 | 9.9 |
| D | | 141.8 | 29.6 | 52.7 | 24.9 | 24.0 | 40.4 | 33.0 | 71.7 | 13.1 | 38.0 | 2.2 | 10.9 | 4.4 | 1.6 | 6.6 | 12.5 |
| log | | 2.9227 | 2.6721 | 2.4698 | 2.7825 | 2.6010 | 2.7101 | 2.2068 | 2.6532 | 2.3598 | 2.6848 | 1.9590 | 1.9395 | 2.3365 | 1.5051 | 2.2430 | 1.9031 |
| T | G | 60.7 | 106.5 | 331.1 | 54.5 | 136.6 | 4.70 | 218.0 | 143.9 | 63.6 | 70.1 | 159.2 | 72.4 | 178.0 | 55.0 | 337.2 | 127.4 |
| D | | 38.5 | 37.1 | 89.4 | 37.8 | 39.9 | 24.3 | 53.8 | 59.3 | 44.3 | 44.2 | 35.5 | 21.9 | 34.1 | 23.9 | 69.6 | 45.8 |
| log | | 2.2014 | 2.4594 | 2.5694 | 2.1614 | 2.5353 | 1.3010 | 2.6085 | 2.3874 | 2.1614 | 2.2041 | 2.6522 | 2.5211 | 2.7185 | 2.3636 | 2.6857 | 2.4456 |
| T | H | 357.0 | 13.0 | 816.8 | 232.8 | 190.3 | 182.7 | 1268.2 | 304.0 | 94.2 | 95.9 | 12.0 | 65.7 | 123.6 | 77.5 | 135.6 | 143.2 |
| D | | 99.8 | 54.3 | 158.9 | 57.3 | 66.6 | 68.2 | 214.2 | 119.5 | 48.1 | 75.8 | 26.8 | 37.4 | 37.4 | 36.3 | 64.2 | 73.7 |
| log | | 2.5551 | 1.3979 | 2.7118 | 2.6090 | 2.4579 | 2.4298 | 2.7731 | 2.4065 | 2.2945 | 2.1072 | 1.6628 | 2.2480 | 2.5198 | 2.3304 | 2.3263 | 2.2900 |
| T | C,D,E,F, | 3627.3 | 295.4 | 1532.2 | 236.3 | 1282.5 | 1821.1 | 2495.1 | 497.2 | 1289.7 | 292.1 | 44.0 | 120.1 | 208.3 | 7.5 | 252.3 | 127.6 |
| D | | 386.8 | 73.4 | 263.0 | 57.7 | 165.9 | 197.2 | 306.5 | 140.9 | 195.1 | 78.1 | 20.5 | 36.5 | 57.7 | 4.9 | 78.2 | 41.4 |
| log | | 2.9727 | 2.6053 | 2.7664 | 2.6138 | 2.8887 | 2.9657 | 2.9112 | 2.5490 | 2.8209 | 2.5740 | 2.3345 | 2.5185 | 2.5587 | 2.1875 | 2.5105 | 2.4900 |

Table IV

Analyses of variance of logs in Table III according to areas, years and seasons

| Analysis | Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|---|
| (i) | Areas | 7 | 1.7931 | 0.2562 |
| | Years | 4 | 0.3371 | 0.0843 |
| | Seasons | 1 | 1.3883 | 1.3883 * |
| | Areas X Years | 28 | 2.6132 | 0.0933 |
| | Areas X Seasons | 7 | 1.6660 | 0.2380 |
| | Years X Seasons | 4 | 0.3390 | 0.0848 |
| | Areas X Years X Seasons | 28 | 7.8155 | 0.2791 |
| (ii) | Areas | 7 | 1.5433 | 0.2205 |
| | Years | 5 | 0.4063 | 0.0813 |
| | Seasons | 1 | 1.2560 | 1.2560 ** |
| | Areas X Years | 35 | 3.6934 | 0.1055 |
| | Areas X Seasons | 7 | 1.2023 | 0.1718 |
| | Years X Seasons | 5 | 0.4835 | 0.0967 |
| | Areas X Years X Seasons | 35 | 3.6520 | 0.1043 |
| (iii) | Areas | 4 | 1.3065 | 0.3266 + |
| | Years | 6 | 0.7193 | 0.1199 |
| | Seasons | 1 | 0.3037 | 0.3037 |
| | Areas X Years | 24 | 2.2427 | 0.0934 |
| | Areas X Seasons | 4 | 0.3367 | 0.0842 |
| | Years X Seasons | 6 | 0.9697 | 0.1616 |
| | Areas X Years X Seasons | 24 | 1.8834 | 0.0785 |

(i), with areas A,B,C,D,E,F,G,H, and years 1953-1957

(ii), with same areas, and same years plus (1958 + 1959)

(iii), with areas A,B,G,H and (C + D + E + F), and years 1953-1959

*significant at P = 0.05, **significant at P = 0.01,

+ almost significant at P = 0.05

Table V

Analyses of variance of logs in Table III according to areas and years

| Analysis | Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|---|
| (i) | Areas | 7 | 1.7019 | 0.2431 ** |
| | Years | 4 | 0.1965 | 0.0491 |
| | Error | 28 | 1.2698 | 0.0454 |
| (ii) | Areas | 7 | 1.7572 | 0.2510 |
| | Years | 4 | 0.4797 | 0.1199 |
| | Error | 28 | 4.1342 | 0.1476 |
| (iii) | Areas | 7 | 1.5353 | 0.2193 ** |
| | Years | 5 | 0.4034 | 0.0807 |
| | Error | 35 | 1.5735 | 0.0450 |
| (iv) | Areas | 7 | 1.2104 | 0.1729 |
| | Years | 5 | 0.4865 | 0.0973 |
| | Error | 35 | 5.7691 | 0.1648 |

(i) as for (i) in Table IV, March-May only

(ii) " " (i) " " IV, June-February only

(iii) " " (ii) " " IV, March-May only

(iv) " " (ii) " " IV, June-February only

* significant at P = 0.05, ** significant at P = 0.01

## Table VI

Yellowfin in the Tehuantepec baitboat fishery in the period December-February; number of tons caught (T), number of standardized fishing days (D) and log ((100 T/D) + 1) by areas and years

| Measure-ment | Area | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1958 + 1959 |
|---|---|---|---|---|---|---|---|---|---|
| T | A | 3.5 | 464.4 | 75.1 | 417.4 | 15.2 | 75.5 | 8.5 | 84.0 |
| D | | 12.2 | 47.8 | 29.4 | 80.9 | 15.0 | 29.8 | 10.5 | 40.3 |
| log | | 1.4771 | 2.9881 | 2.4082 | 2.7135 | 2.0086 | 2.4048 | 1.9138 | 2.3201 |
| T | B | 8.4 | 28.0 | 72.0 | 772.7 | 44.1 | 290.9 | 18.2 | 309.1 |
| D | | 17.4 | 9.3 | 9.3 | 141.9 | 16.6 | 46.4 | 9.4 | 55.8 |
| log | | 1.6902 | 2.4800 | 2.8893 | 2.7372 | 2.4265 | 2.7980 | 2.2900 | 2.7443 |
| T | C | 93.8 | 0.0 | 6.5 | 18.4 | 0.0 | 18.0 | 0.0 | 18.0 |
| D | | 15.3 | 1.5 | 5.7 | 11.2 | 1.8 | 3.0 | 0.5 | 3.5 |
| log | | 2.7882 | 0.0000 | 2.0607 | 2.2175 | 0.0000 | 2.7789 | 0.0000 | 2.7118 |
| T | D | 0.5 | 13.0 | 520.6 | 10.2 | 0.5 | 78.5 | 7.0 | 85.5 |
| D | | 3.5 | 3.0 | 41.7 | 2.9 | 1.2 | 6.2 | 1.3 | 7.5 |
| log | | 1.1761 | 2.6375 | 3.0965 | 2.5478 | 1.6335 | 3.1028 | 2.7316 | 3.0573 |
| T | E | 24.2 | 51.5 | 1084.7 | 80.0 | 54.5 | 10.0 | 0.0 | 10.0 |
| D | | 12.8 | 7.1 | 98.4 | 23.0 | 15.2 | 10.9 | 0.0 | 10.9 |
| log | | 2.2788 | 2.8609 | 3.0425 | 2.5428 | 2.5563 | 1.9685 | 0.0000 | 1.9685 |
| T | F | 138.9 | 150.7 | 202.8 | 317.5 | 112.1 | 3.4 | 0.5 | 3.9 |
| D | | 27.5 | 23.4 | 36.2 | 66.4 | 27.8 | 8.5 | 1.6 | 10.1 |
| log | | 2.7042 | 2.8096 | 2.7490 | 2.6803 | 2.6064 | 1.6128 | 1.5051 | 1.6021 |
| T | G | 65.5 | 7.0 | 0.0 | 39.5 | 26.9 | 9.5 | 29.0 | 38.5 |
| D | | 18.0 | 6.1 | 10.9 | 23.7 | 15.1 | 9.6 | 11.3 | 20.9 |
| log | | 2.5623 | 2.0645 | 0.0000 | 2.2253 | 2.2529 | 2.0000 | 2.4116 | 2.2672 |
| T | H | 12.0 | 77.1 | 168.2 | 265.4 | 42.5 | 41.5 | 47.5 | 89.0 |
| D | | 29.5 | 23.0 | 55.6 | 86.0 | 37.4 | 30.6 | 22.2 | 52.8 |
| log | | 1.6232 | 2.5263 | 2.4829 | 2.4914 | 2.0607 | 2.1367 | 2.3324 | 2.2304 |
| T | C,D,E | 118.5 | 64.5 | 1611.8 | 108.6 | 55.0 | 106.5 | 7.0 | 113.5 |
| D | | 31.6 | 11.6 | 145.8 | 37.1 | 18.2 | 20.1 | 1.8 | 21.9 |
| log | | 2.5752 | 2.7459 | 3.0437 | 2.4683 | 2.4814 | 2.7251 | 2.5911 | 2.7152 |

These results agree with the hypothesis in showing that yellowfin are consistently and significantly more plentiful in area C and D, especially D, than in other areas to the east, north and west, in the latter part of the Tehuantepecer season. It is not shown, however, that this applies to area E.

From the original hypothesis a similar result would be expected for the period December-February, but it cannot be demonstrated. Table VI lists the logged means of catch per day for this period for the different years and areas; several of these means have low bases because fishing effort is lower in December-February than in March-May. Table VII gives the results of an analysis of variance on 36 means which were chosen so that only five of them were based <10>5 days. Neither the area nor the year effect is significant.

It is noteworthy that no significant year effect or area-year interaction appears in any analysis of yellowfin data.

5.2 Skipjack

Tables VIII and IX present catch and catch per day data for skipjack in the way that Tables I and II do for yellowfin: numbers of days are the same for both species and therefore not repeated in Tables VIII and IX. The mean catch per day of skipjack for all areas and seasons is 0.87 tons (Table IX); the corresponding figure for yellowfin is 4.62 tons (Table II). The seasonal and spatial distribution is quite different in the two species: for instance, skipjack catch per day in the combined areas is higher in September-November than in any other quarter-year, and for the combined seasons it is higher in B and A than in any other areas.

For further study by analysis of variance the 1953-1959 data are assembled in Table X, corresponding to Table III for yellowfin. This brings out the fact that skipjack were absent from most areas after February 1957, and absent from all areas except B after February 1958. It was therefore appropriate to confine the analysis to the four years 1953 to 1956, with eight areas and two seasons as for yellowfin in Table IV (i) (ii); two of the 64 means were based on <10>5 days. Table XI gives the results: only the year effect is significant. The season effect is practically unmeasurable for these data, but Table IX strongly suggests that a different result would have been obtained if 1951 and 1952 data had been included, or if a different grouping of quarter-years had been made; these things were not done, as explained in connection with the yellowfin analyses, because they would have introduced many more low-based means. It is probably safe to conclude that skipjack are more abundant in the half-year June-November than in December-May, which is the opposite of the situation for yellowfin. Nothing can be said with confidence about differences between areas but differences between years are manifest; in these respects again the distribution of skipjack differs markedly from that of yellowfin. The hypothesis developed above obviously is not true for skipjack.

A D test of differences between year means showed that catch per day was not significantly different between 1954, 1955, and 1956, whereas it was significantly higher in each of those years than it was in 1953. In 1957, 1958, and 1959, the catch per day was virtually nil, as mentioned above.

6 DISCUSSION

It has been shown that the original hypothesis about distribution and abundance of tuna by season and area, derived from oceanography with the aid of certain assumptions as explained in section 4, is partly supported by the most trustworthy yellowfin data. It is not at all supported by skipjack data. The hypothesis did not deal with possible changes from year to year: in the outcome such effects appear to be negligible for yellowfin and very important for skipjack.

Specifically, the yellowfin data agree with the preliminary hypothesis in that areas C and D, which normally cover the southern part of the pycnocline ridge and waters immediately west of it, have a significantly higher catch per day than other areas further east, north, and (in the case of area D) west, in the last two or three months of the Tehuantepecer season. They disagree with the hypothesis in that (i) they show no similar difference for the peak of the Tehuantepecer season, or (ii) for area E at any time, and (iii) that changes in catch per day for the whole region occur about three months later than the supposedly related changes in the weather and ocean cycle. Of these three points of disagreement, (ii) is the least serious; it could merely mean that the highest concen-

Table VII

Analysis of variance of logs in Table VI for areas A, B, F, G, H and (C + D + E), and years 1953-1958

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Areas | 5 | 2.5542 | 0.5108 |
| Years | 5 | 1.0753 | 0.2151 |
| Error | 25 | 7.4917 | 0.2997 |

## Table VIII

Skipjack in the Tehuantepec baitboat fishery, March 1951-February 1960; number of tons caught (T) by areas and months; see Table I for number of standardized fishing days (D): tons per day (T/D) shown for combined areas in each month

| Measure-ment | Area | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | 0 | 0.0 | 0.0 | 0.0 | 8.0 | 0.0 | 0.7 | 20.8 | 2.0 | 3.0 | 50.8 | 0.0 | 0.0 |
| T | A | 10.2 | 2.6 | 47.3 | 60.7 | 58.8 | 104.5 | 431.6 | 82.1 | 35.0 | 258.2 | 1.2 | 58.7 |
| T | B | 1.0 | 49.9 | 6.5 | 66.9 | 99.9 | 519.4 | 60.9 | 42.6 | 280.3 | 643.8 | 47.5 | 0.0 |
| T | C | 0.0 | 3.5 | 38.8 | 108.7 | 108.3 | 5.0 | 1.0 | 30.9 | 56.0 | 21.0 | 5.0 | 3.3 |
| T | D | 0.0 | 84.0 | 162.7 | 89.2 | 45.0 | 1.5 | 2.0 | 0.0 | 0.0 | 0.0 | 3.0 | 0.0 |
| T | E | 4.8 | 198.0 | 140.0 | 73.0 | 6.5 | 0.0 | 4.0 | 0.0 | 0.0 | 65.0 | 0.0 | 62.5 |
| T | F | 17.1 | 67.7 | 2.5 | 120.6 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 22.0 | 2.0 | 254.8 |
| T | G | 0.0 | 0.0 | 40.4 | 27.9 | 20.8 | 16.2 | 0.0 | 108.3 | 60.5 | 14.0 | 0.0 | 0.0 |
| T | H | 23.0 | 28.4 | 181.1 | 92.0 | 30.0 | 0.0 | 2.2 | 21.5 | 26.4 | 50.0 | 0.0 | 15.0 |
| T | Total | 56.1 | 434.1 | 619.3 | 647.0 | 372.8 | 647.3 | 522.5 | 287.4 | 461.2 | 1124.8 | 58.7 | 394.3 |
| T/D | | 0.13 | 0.49 | 0.52 | 0.49 | 0.30 | 1.58 | 2.03 | 1.88 | 3.59 | 5.84 | 0.39 | 2.61 |

Table IX

Data of Table VIII (skipjack) grouped by three-month periods; see Table II for number of standardized fishing days (D)

| Measure-ment | Area | Dec.-Feb. | Mar.-May | June-Aug. | Sept.-Nov. | Total |
|---|---|---|---|---|---|---|
| T | O | 0.0 | 8.0 | 23.5 | 53.8 | 85.3 |
| T/D | | 0.00 | 0.11 | 1.13 | 3.74 | 0.59 |
| T | A | 71.5 | 166.8 | 618.2 | 294.4 | 1150.9 |
| T/D | | 0.27 | 0.40 | 2.54 | 3.13 | 1.13 |
| T | B | 50.9 | 173.3 | 622.8 | 971.6 | 1818.6 |
| T/D | | 0.19 | 0.34 | 2.80 | 5.48 | 1.55 |
| T | C | 6.8 | 255.8 | 36.9 | 82.0 | 381.5 |
| T/D | | 0.16 | 0.66 | 0.98 | 4.88 | 0.78 |
| T | D | 84.0 | 296.9 | 3.5 | 3.0 | 387.4 |
| T/D | | 1.40 | 0.80 | 0.18 | 0.52 | 0.85 |
| T | E | 265.3 | 219.5 | 4.0 | 65.0 | 553.8 |
| T/D | | 1.58 | 0.51 | 0.19 | 3.78 | 0.87 |
| T | F | 339.6 | 126.6 | 0.0 | 24.0 | 490.2 |
| T/D | | 1.77 | 0.39 | 0.00 | 1.89 | 0.90 |
| T | G | 0.0 | 89.0 | 124.5 | 74.5 | 288.0 |
| T/D | | 0.00 | 0.18 | 1.12 | 1.36 | 0.37 |
| T | H | 66.4 | 303.2 | 23.8 | 76.4 | 469.8 |
| T/D | | 0.21 | 0.42 | 0.18 | 1.00 | 0.38 |
| T | Total | 884.5 | 1639.1 | 1457.2 | 1644.7 | 5625.5 |
| T/D | | 0.61 | 0.44 | 1.78 | 3.50 | 0.87 |

## Table X

Skipjack in the Tehuantepec baitboat fishery, March 1953-February 1960; number of tons caught (T) and log ((100. T/D) + 1) by areas, years and seasons; see Table III for number of standardized fishing days (D)

| Measure-ment | Area | 1953 | | 1954 | | 1955 | | 1956 | | 1957 | | 1958 | | 1959 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. | Mar.-May | June-Feb. |
| T | A | 4.0 | 3.0 | 11.9 | 162.6 | 56.5 | 106.3 | 39.4 | 205.7 | 55.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 1.1761 | 1.0792 | 1.4472 | 2.1584 | 1.8808 | 2.3747 | 1.8195 | 2.2041 | 1.6435 | 0.6021 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| T | B | 6.7 | 3.0 | 64.9 | 485.8 | 52.0 | 38.8 | 23.4 | 936.8 | 6.3 | 12.2 | 0.0 | 5.2 | 0.0 | 4.0 |
| log | | 1.0414 | 0.9542 | 2.1072 | 2.6222 | 1.6812 | 2.1106 | 1.7993 | 2.5809 | 0.8451 | 1.3979 | 0.0000 | 0.9542 | 0.0000 | 0.9542 |
| T | C | 26.0 | 5.3 | 108.3 | 0.5 | 84.7 | 2.0 | 36.8 | 110.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 1.8513 | 1.4314 | 2.0864 | 0.7782 | 2.1206 | 1.3222 | 2.1072 | 2.6444 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| T | D | 3.0 | 3.5 | 46.0 | 1.5 | 85.2 | 85.5 | 162.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 0.6021 | 1.7243 | 1.8325 | 1.1761 | 2.4698 | 2.2856 | 2.1399 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| T | E | 59.1 | 0.0 | 9.1 | 10.0 | 14.4 | 191.8 | 136.9 | 129.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 1.6990 | 0.0000 | 1.2788 | 1.9494 | 1.4914 | 2.2765 | 2.0414 | 2.5391 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| T | F | 41.2 | 59.8 | 75.0 | 0.0 | 4.4 | 53.9 | 5.5 | 248.9 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 1.4771 | 2.3075 | 2.1553 | 0.0000 | 1.2788 | 2.1271 | 1.2553 | 2.5416 | 0.0000 | 0.6021 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| T | G | 2.0 | 0.0 | 20.8 | 38.1 | 3.2 | 1.2 | 63.0 | 155.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 0.7782 | 0.0000 | 1.3802 | 2.0086 | 0.9542 | 0.7782 | 2.0719 | 2.4216 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| T | H | 72.4 | 3.0 | 34.0 | 77.5 | 14.3 | 15.0 | 182.5 | 69.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| log | | 1.8692 | 0.8451 | 1.3424 | 2.1335 | 1.3424 | 1.3617 | 1.9345 | 1.7709 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

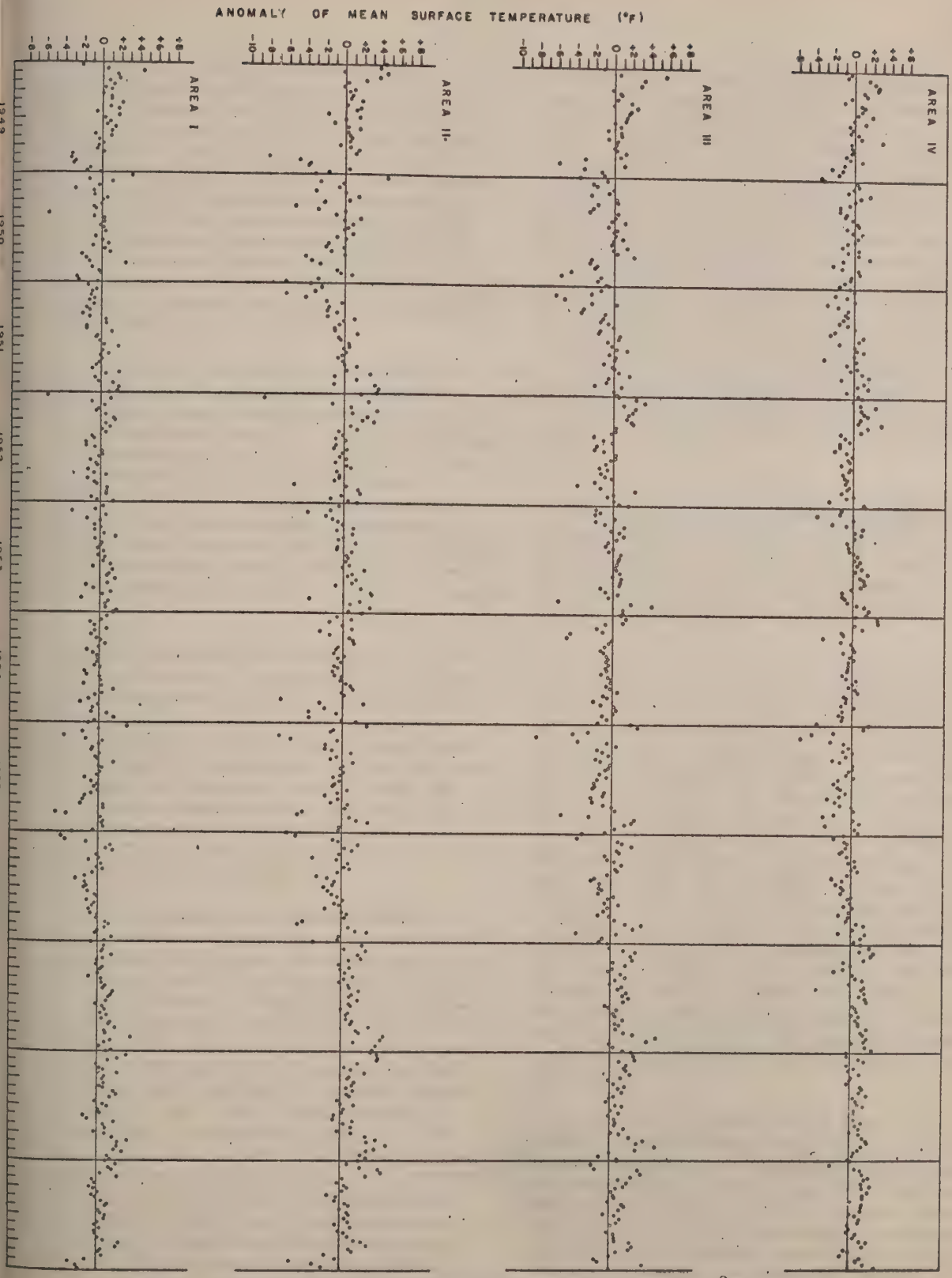


Fig. 4 Anomalies of 10-day means of surface temperature ($^{O}$F), from means for corresponding periods based on all 1949-1959 data, in areas I-IV of Fig. 3

trations of biota do not regularly extend into area E, although they did so on some of the past cruises. The other two points of disagreement, (i) and (iii), would disappear if it could be shown that the annual cycle of abundance of tuna prey lags about three months behind the annual cycle of weather and associated ocean conditions described above. This cannot be shown, but it is not an unreasonable assumption since yellowfin feed mainly on small nekton, which might well have an average age of the order of three months; it amounts to a virtual denial of the unsupported point (b) in section 4.

The hypothesis may therefore be modified accordingly, until it can be further tested. It still says that yellowfin are distributed according to the distribution of their food in space and time, and this distribution can be understood in some detail by reference to a series of oceanic phenomena connected with the annual weather cycle; but it now assumes a lag of about three months between changes at the physical, chemical, and lower biological levels on the one hand, and changes at the higher biological levels on the other.

There is no evidence of difference in distribution and abundance of yellowfin at any one season over the seven-year period 1953-1959. Admittedly the fishing effort was smaller in 1958 and 1959 than in the previous years, and this necessitated a grouping of data for analysis which might have obscured a small difference in catch per day between those two years, or between them and the other years; but it may confidently be said that there was no large difference over the whole period.

This is of considerable interest because there were marked differences in the only other property of the Gulf waters for which data exist over the same period, namely surface temperature. Fig. 4 shows for each of four areas that surface temperatures were average in 1953, low in 1954 and 1955, low or average in 1956, high in 1957 and 1958, and high or average in 1959; similar variations occurred in the four previous years (high in 1949, low in 1950, average in 1951 and 1952); the variable in Fig. 4 is the anomaly for a given 10-day period based on the 1949-1959 average for the period. The reasons for this series of changes are not understood, although its likeness to contemporaneous series in other parts of the eastern Pacific has been pointed out (Blackburn and associates 1962).

No consistent differences are observable between winter (Tehuantepecer season) and summer anomalies of surface temperature in the same year. Similar records of wind velocity (unspecified as to direction, but considered as northerly in the winter months) show no obvious departure from the long-term average for a given time of year in any of the years (Fig. 5). It may be concluded that the annual cycle of local weather is regular; that this circumstance (referring to the observations and argument above) imposes a regularity upon the annual cycle of distribution and abundance of yellowfin; and that this regularity in the yellowfin cycle is normally undisturbed by the longer-period oceanic changes that affect surface temperatures in the Gulf and other parts of the eastern Pacific from time to time.

The areas (I-IV) referred to in Figs. 4 and 5 were chosen to give the longest possible series of adequately-based 10 day means (see Roden 1961 for previous work on some of these data). The original data were provided by the United States Weather Bureau. The areas are shown in Fig. 3.

There are several points of correspondence between the major changes in surface temperature anomaly with time in these areas (Fig. 4) and the above-mentioned time changes in skipjack catch per day. Catch per day was lower in 1953 (temperature generally average in areas I-IV) than it was in 1954-1956 (temperature generally lower than average in areas I-IV, except in area III where it was average in 1956), and then declined very greatly in 1957-1959 (temperature generally higher than average in areas I-IV, except in areas I and II where it was average in 1959). The change from low to high temperature occurred about the beginning of 1957, and the change in skipjack catch per day occurred at about the same time (Table X). The temperature increased least in area I; this includes part of area B, the only area in which some skipjack remained through 1957 to 1959 (Table X).

It is therefore probable that there is an inverse relation between surface temperature (actual temperature or anomaly) and skipjack abundance over a certain range of the former, with skipjack abundance falling to zero above a certain temperature (or anomaly) in a way that suggests exclusion of the fish by the temperature. Detailed investigation of this relationship would

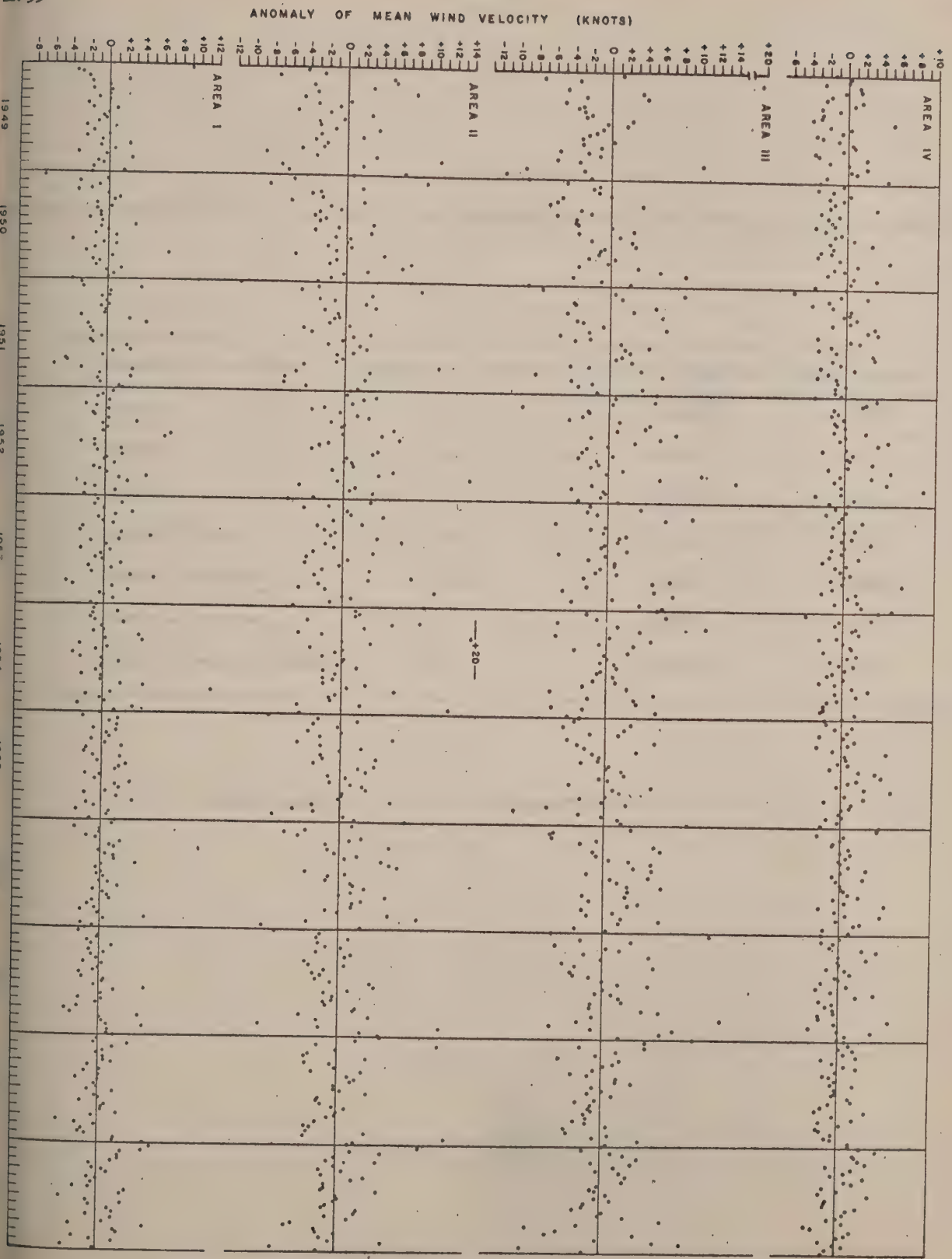


Fig. 5 Anomalies of 10-day means of wind velocity (knots), from means for corresponding periods based on all 1949-1959 data, in Areas I-IV of Fig. 3

Table XI

Analysis of variance of logs in Table X according to years (1953-1956 only), areas and seasons

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Areas | 7 | 1.7768 | 0.2538 |
| Years | 3 | 5.5744 | 1.8581* |
| Seasons | 1 | 0.0000 | 0.0000 |
| Areas X Years | 21 | 8.6245 | 0.4107 |
| Areas X Seasons | 7 | 1.6485 | 0.2355 |
| Years X Seasons | 3 | 0.6025 | 0.2008 |
| Areas X Years X Seasons | 21 | 10.6776 | 0.5084 |

* significant at P = 0.05, ** significant at P = 0.01

require the temperature and skipjack data to be reassembled into a single set of areas and periods, which has not yet been done. Such investigations may throw some light on the distribution of skipjack by areas and seasons as well as years.

As shown above, it is unlikely that any similarly close relationship exists between surface temperature and yellowfin; Table III shows that yellowfin did not disappear in the warm years as the skipjack did, and there is no evidence of any change in their abundance in those years.

It was shown that the area effect is significant and the year effect not significant for yellowfin catch per day in the period March-May (section 5.1, Table V), despite marked differences in surface temperature between several of the years; the area effect was that catch per day in areas C and D was higher than in several other areas and not surpassed in any. It is therefore probable that fishermen could obtain a higher catch of yellowfin per day in areas C and D than in other areas at the period March-May, which is the height of the yellowfin fishing season. Their own past experience shows this kind of distribution in the years 1953 to 1959, and the explanation through oceanography provides reasonable assurance that the distribution will recur in any year in which weather and ocean conditions fall within the range observed in 1953 to 1959. Tables I to III show that lower baitboat fishing effort is expended in areas C and D than in most other areas; this is partly because these areas are particularly exposed to northerlies, which might limit purse-seine fishing even more than baitboat fishing. The fishermen would probably find it more profitable to seek yellowfin in areas C and D than elsewhere in the Gulf region, whenever weather conditions offer them the choice, in the period March-May of any year. Of course the catch per day levels of 1953 to 1959 could not be expected if the yellowfin populations declined for reasons unaffected by the environment, e.g. by overfishing; but however abundant the fish are, they will tend to be more plentiful in areas C and D than in the other areas considered in this paper.

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Experience Paper No. 34

# STUDIES OF OCEANIC FRONTS IN THE MOUTH OF THE GULF OF CALIFORNIA, AN AREA OF TUNA MIGRATIONS

By

RAYMOND C. GRIFFITHS

Scripps Institution of Oceanography
University of California at San Diego,
La Jolla, California, U.S.A.

## Abstract

A review of the literature shows that it is widely believed that small biota (e.g. plankton, micronekton) and pelagic fish tend to be especially abundant at fronts, but few detailed studies of this have been made. The present paper shows the distribution of physical and biological oceanographic properties at certain fronts in a region through which tuna migrate.

Fronts in the mouth of the Gulf of California may be formed, in the upper 120 m, by two of three types of water: (i) Gulf of California; (ii) California Current; (iii) equatorial Pacific. The front best developed and studied is off Cape San Lucas, Lower California, in spring and summer; the cool, low-salinity, upwelled water contrasts well with the warm, saline Gulf water. Vertically, this front has a Z-shaped interface.

Biological property distributions show that certain kinds of biota were more numerous in the middle of this front than on either side, and may therefore have been accumulated by convergence at the front. Marlin were observed in the area at the time of the observations, but tuna were not. Commercial catch and effort data on yellowfin are available by one-degree rectangles and by months, but this scale is too gross to show any clear relation to the front.

# ETUDES DES FRONTS OCEANIQUES A L'ENTREE DU GOLFE DE CALIFORNIE, ZONE DE MIGRATION DU THON

## Résumé

L'examen de la bibliographie montre que l'abondance particulière sur les fronts océaniques de petits biota et de poissons pélagiques est une idée très largement répandue, mais qu'il y a peu d'études de détail à ce sujet. Cet article traite de la distribution des propriétés océanographiques, physiques et biologiques, sur certains fronts dans une zone où migrent les thons.

Les fronts à l'entrée du golfe de Californie peuvent être formés dans les 120 m supérieurs par deux de trois types d'eaux: (i) golfe de Californie, (ii) courant de Californie, (iii) Pacifique équatorial. Le front le plus développé et le mieux étudié

est au large du Cap San-Lucas, Basse Californie, au printemps et en été; l'eau de remontée, froide et de faible salinité, contraste nettement avec l'eau chaude et salée du golfe. Sur le plan vertical ce front présente une interface en forme de Z.

La distribution des propriétés biologiques montre que certains types de biota sont plus nombreux dans la partie médiane de ce front que sur les autres côtés et pourraient avoir été accumulés en conséquence par une convergence sur ce front. On a noté la présence de marlin dans cette zone au cours des observations, mais non celle du thon. On dispose de données sur le volume de capture et sur l'effort de pêche dans des rectangles d'un degré et par mois, mais cette échelle est trop large pour qu'on puisse déceler une relation nette avec le front.

## ESTUDIOS DE LOS FRENTES OCEANICOS EN LA BOCA DEL GOLFO DE CALIFORNIA, ZONA DE EMIGRACIONES DEL ATUN

Extracto

Un examen de la literatura revela que está muy difundida la idea de que la biota pequeña y los peces pelágicos tienden a abundar especialmente en los frentes oceánicos, pero de ello se han hecho pocos estudios profundos. En esta ponencia se da a conocer la distribución de propiedades oceanográficas físicas y biológicas en ciertos frentes de una región por la que emigra el atún.

En la boca del Golfo de California pueden formar frente, en los 120 m. superiores, dos de tres clases de agua: (i) del Golfo de California; (ii) de la corriente de California; (iii) del Pacífico ecuatorial. El frente más claro y mejor estudiado es el del Cabo San Lucas, Baja California, en primavera y verano; el agua de surgencia fría y de baja salinidad contrasta con la cálida y salina del Golfo. Verticalmente este frente tiene una superficie en forma de Z.

La distribución de las propiedades biológicas demuestra que ciertas clases de biota son más numerosas en el centro que en los lados de este frente y es posible, por lo tanto, que se hayan acumulado por convergencia. Al hacerse las observaciones se vio pez aguja en la zona, pero no atunes. Se dispone de datos de captura industrial y de esfuerzos de pesca de atún de aleta amarilla en rectángulos de un grado y por meses, pero esta escala es demasiado grosera para mostrar una relación clara con el frente.

## 1 INTRODUCTION

The most prominent oceanographic features of the entrance to the Gulf of California, though they vary considerably in time, space, and intensity, are oceanic fronts, found usually near Cape San Lucas at the southern end of Lower (Baja) California and sometimes at Cape Corrientes (Fig. 1).

There is no precise definition in oceanography of the term "front", which has apparently been widely adopted from meteorologists. Cromwell and Reid (1956) say "A front will mean a band along the sea surface across which density changes abruptly". This definition has the advantage that it does not particularize the more readily measured properties (temperature and salinity) that determine the density change. As a rule, assuming that the front is not visible, it is best indicated by a thermograph. It is quite possible for the density change to be due entirely to salinity differences, however. This leads to the use of such terms as temperature fronts and salinity fronts.

Uda (1959) appears to take the view that a front (siome) is a boundary between two different kinds of water. He says, "Then the boundaries of the water mass are in the region where the gradients of the property are maximum (i.e. the Polar Fronts, etc.)".

La Fond (1961) uses the following definition: "The leading edge of a border separating unlike water masses is called a front. Fronts can occur not only between water masses of different salinity but also between those differing in other properties, such as temperature".

The term "water mass" in these definitions is used loosely, not necessarily in conformity with Sverdrup, Johnson, and Fleming (1942). For example, fronts are often found between upwelled water and non-upwelled water, both kinds pertaining to one water mass in the sense of Sverdrup et al.

Uda (1959) specifies a front, in terms of a temperature gradient, as varying from 0.5°C/10 miles to 5.0°C/10 miles. This tenfold difference between limits illustrates the inevitable lack of precision in any definition of an oceanic front.

The best known fronts (perhaps better called frontal systems, using the word front for sections of those systems that we investigate) are those between the cool, low-salinity polar waters and the warm, more saline, subtropical waters: the Arctic and Antarctic Convergences; and those between the Equatorial Counter-current and the North and South Equatorial Currents. Lesser known but important fronts occur between the Baltic outflow and the North Sea; between the outflow from the Gulf of California and the California Current and/or equatorial Pacific waters; and in regions of upwelling. These few examples cover a wide range of dimension and motion, and cannot be freely compared amongst themselves; they represent only a small selection of all known frontal areas (see Uda 1938). The zone of mixing between the Kuroshio and the Oyashio (and between the Gulf Stream and the Labrador Current) is so vast in certain times and places that some workers refer to the front between Kuroshio and mixed water as the Kuroshio front, and to that between the Oyashio and the mixed water as the Oyashio front; a similar distinction may be made in the western Atlantic where the mixed water is called Shelf water.

Important contributions to the knowledge of the front between the Kuroshio and the Oyashio have been made by Beklemishev and Burkov (1958); Burkov and Arseniev (1958); Fukuoka (1955); Hanzawa (1952); Kawai (1955); Masuzawa (1955a, 1955b); Siomina (1958); Uda (1938, 1943, 1953, 1954, 1955, 1958, 1959, 1961); Uda and Ishino (1958); and others. Important work on the Gulf Stream front has been done by Ford and Miller (1952); Fuglister (1951); Fuglister and Worthington (1951); Iselin and Fuglister (1948); Spilhaus (1940); Von Arx, Bumpus and Richardson (1955); and many others. The equatorial frontal systems have been studied by Austin (1960); Cromwell (1953, 1958); Cromwell and Reid (1956); King and Hida (1957); and others. Wyrtki (1960a, 1960b) and Mackintosh (1946) have contributed significantly to the understanding of the Antarctic polar front.

Although fronts are common off the coast of California and Lower California (as off any coast where upwelling is strong), study of them has been casual and incidental to the quasi-synoptic surveys of the whole region made by the California Co-operative Oceanic Fisheries Investigations (Cal.C.O.F.I.).

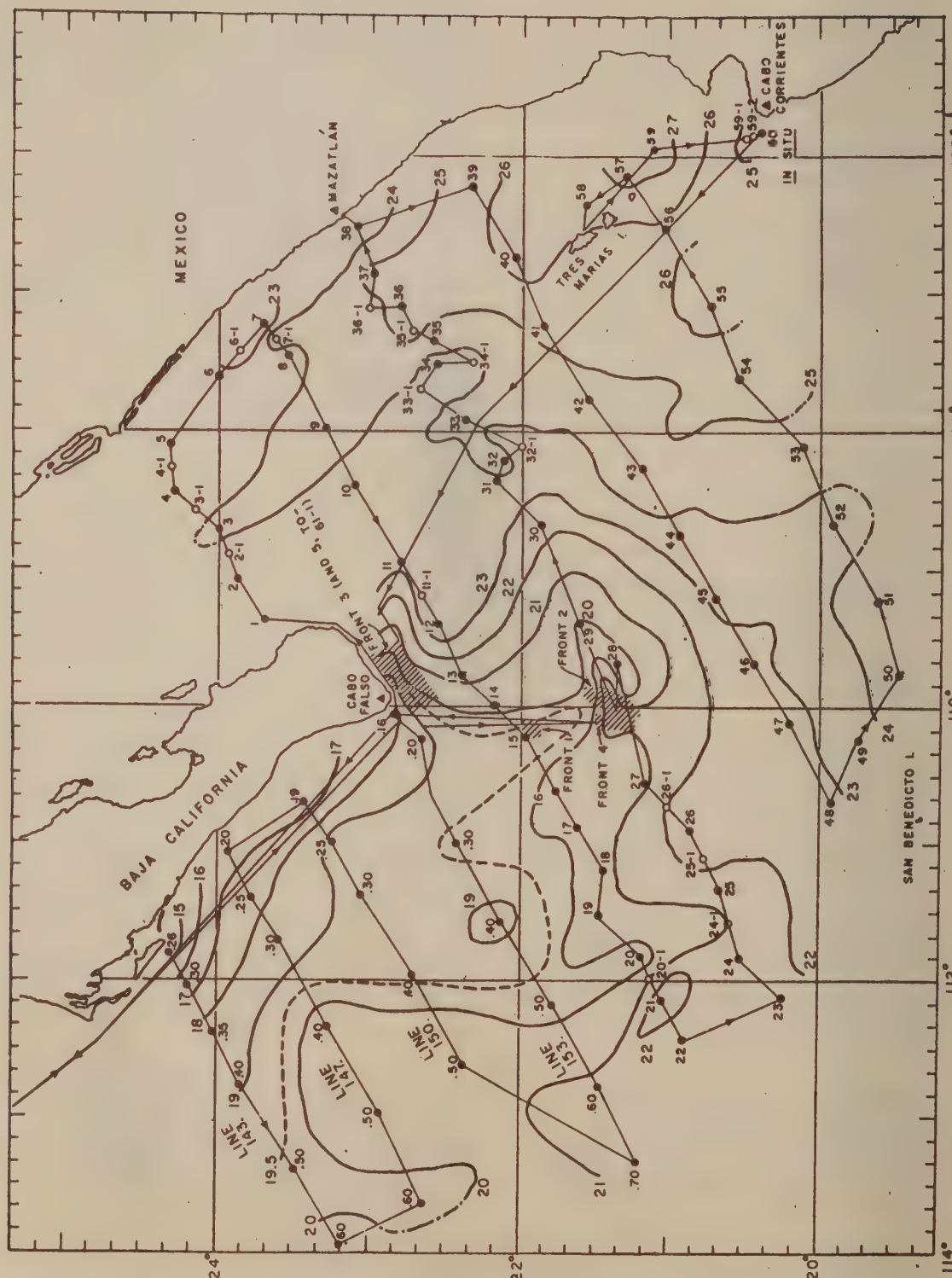


Fig. 1 A map showing the track of the S.T.O.R. cruise TO-60-1 (stations 1

The view that convergent fronts aggregate plankton is apparently rather widely held. Uda (1938) describes the accumulation of flotsam at siome, or fronts, and Uda and Ishino (1958) indicate that convergent fronts show a line of biological demarcation owing to aggregation of biota. They go on to show the relationship of fisheries for albacore (Germo germo), skipjack (Katsuwonus pelamis) and bluefin (Thunnus orientalis) to the front between the cool Oyashio and the warm Kuroshio. La Fond (1961) continuing his definition, started above, says, "These fronts raise water of higher nutrient content to the surface. In addition, the fronts tend to concentrate floating fish food in adjacent areas". This raises the question of whether a front manifests a higher standing crop of plankton than does water on either side by aggregating the biota or by causing conditions specially favorable to the growth of a higher standing crop. This, in turn, probably depends on whether the front is convergent, in which case aggregation might be expected, or divergent, in which case nutrient-rich water might be brought to the surface to increase plankton growth. Uda (1959) suggests that the latter occurs at siome (p. 18 op. cit.) although those he discusses are apparently of the convergent type. Evidently, there is some conflict of possibilities. Siomina (1958) states that phytoplankton "blooms" are a feature of the area of mixing between the Kuroshio and Oyashio; whether these "blooms" are the result of in situ production or of mechanical aggregation is not stated. Perhaps both causes are responsible, with the in situ production being the more important.

King and Hida (1957) show, on a relatively large scale, a relation between high standing crop of zooplankton and the frontal system in the central equatorial Pacific, without, however, establishing the actual cause of the high plankton values. Indeed, the peak values are slightly south of the three fronts (parts of the system) they studied. Their results also show a somewhat lower quantity of plankton in the convergence zone ($2^{\circ}$ - $4^{\circ}$N) than in the divergence zone ($2^{\circ}$S - $2^{\circ}$N). Beklemishev and Burkov (1958) show, from data obtained by the R/V Vitiaz, that plankton is more abundant in the zone of contact between the Oyashio and the Kuroshio than to either side, and that this plankton comprises forms from both biotopes (cool, low-salinity and warm, high-salinity). The zone of mixing is about four hundred miles wide, however, in the area studied. These authors further say: "The quantity of species in the zone of mingling of water masses sometimes turns out to be greater than each separately (Siomina 1957)". 1/

Some relatively precise results, kindly lent me by Mr. T. S. Austin of the United States Fish and Wildlife Service, show catches of zooplankton hauls within five to ten miles of a front in the equatorial central Pacific. The highest catches were in the front and on the warm side (about five miles away); the volumes fell off beyond that but were roughly the same five miles away on the cool side and ten miles away on the warm side. Again, these data do not indicate the cause of the plankton distribution. Knauss (1957), writing of a front apparently between South Equatorial Current water and Equatorial Counter-current water, says, "High biological activity was associated with the front; however, there was no floating debris. The cold water was relatively sterile; most of the life appeared to be concentrated in the relatively narrow frontal zone". These biological observations were made only by dipnet.

There is a definite relation between fish abundance and fronts, according to Uda (1953, 1954, 1959 and 1961). Japanese fisheries for bluefin, albacore and skipjack are closely related to the front between the Oyashio and the Kuroshio (Uda and Ishino 1958). The local Japanese whale fishery is also related to this large frontal system (Uda 1938, 1954). The front between the Gulf Stream and the Labrador Current is not the focus of intense fishing such as there is off Japan, perhaps because fisheries are well developed on the larger continental shelf in the western Atlantic. Nevertheless, tuna are strongly associated with the Gulf Stream front (Walford 1958; Rivas 1955).

Eggvin (1940) discusses the advance of a cold front of Baltic water through the Skagerrak, northwards along the Norwegian coast in the early spring; this is an example of a negative relationship, however, for the cold, low-salinity water drives spawning herring (Clupea harengus)

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1/ These authors do not give a publication by Siomina for 1957 in their literature citations, but do give one by him for 1958, which seems to be appropriate to their statement. This is included in the literature cited for the present paper.

offshore and out of their usually favored habitats; this phenomenon varies from year to year, causing annual fluctuations in the recruitment. Robins (1952) shows a marked increase in troll catches of skipjack tuna in a front (a relatively weak one) in the entrance to Storm Bay, Tasmania.

Although fronts have commanded the interest of oceanographers in general, relatively little detailed work has been done on them (disregarding the large-scale studies of the major frontal systems), especially from a biological point of view. The investigations already mentioned are overwhelmingly physical and dynamical. Quantitative biological measurements in relation to fronts, especially of the smaller, sharper kind, are scant in the literature.

The fronts studied by Scripps Tuna Oceanography Research group (S. T. O. R.) are described below. They have two points of general interest: i) they have, judging from the literature, been more completely studied than any others (though not necessarily in any particular detail); ii) they occur in an area that yellowfin (Neothunnus macropterus) and possibly skipjack tuna normally migrate across at a time of year when the fronts are best developed. Hence, these studies contribute to our knowledge of a relatively ill-known phenomenon; and the fronts may have an influence on the seasonal movement of tuna into the "local banks" fishery off the west coast of Lower California, though we do not know this yet.

A manuscript describing in detail the fronts studied by the S. T. O. R. group is being prepared for publication in the Special Scientific Report - Fisheries Series of the United States Department of the Interior, Fish and Wildlife Service. Many figures and data from that manuscript that cannot be presented in this paper are drawn upon freely here for the purpose of discussion.

## 2 OCEANOGRAPHIC CRUISES

S. T. O. R. cruise TO-60-1 (30 April – 27 May, 1960) was made to study the physical, chemical and biological properties of the entrance to the Gulf of California at a time when, normally, yellowfin and possibly skipjack tuna are migrating from the west coast of the Mexican mainland across or into the Gulf of California and thence to the west coast of Lower California (Alverson 1960; Griffiths 1960; Inter-American Tropical Tuna Commission Annual Reports, 1960 and 1961). Complementing this survey was a study of oceanic fronts known to be common there (Reid, Roden and Wyllie 1958; Roden and Groves 1959).

Using the experience gained in the observations of the four fronts studied on TO-60-1, further study was made of one of them (at Cape San Lucas) at the end of S. T. O. R. cruise TO-61-1 (19 - 24 April, 1961). The results obtained for this latter study form the body of this paper.

Apart from the S. T. O. R. cruises to the mouth of the Gulf, there are a number of Cal C. O. F. I. cruises which went either into the Gulf or down to Cape San Lucas; these have been used to gain an idea of the variation in time and space of the Cape San Lucas front. These cruises, numbered by year and month, with Scripps Data Report references, are: 5011 (51-47), 5109 (51-38), 5401 (58-38), 5412 (60-), 5501 (59-36), 5502 (59-36), 5503 (59-37) 5512 (60-4), 5601 (60-5), 5602 (60-5), 5604 (60-6), 5612 (61-22), 5702 (58-22), 5704 (58-24), 570 (58-33), 5708 (58-63), 5801 ( 59-3), 5908 (61-9 6001 (61-23), and 6004 (62-6). Data from the Vermilion Sea Expedition, 13 April to 29 May 1959 (60-51), were also used.

## 3 RESULTS

### 3.1 The General Area

Fig. 1 shows the track of cruise TO-60-1 and part of Cal. C. O. F. I. cruise 6004 (MV Black Douglas), which ended at Cape Falso (about west of Cape San Lucas) on 30 April 1960. The surface isotherms and areas in which fronts (1, 2, 3, 4 and 5) were studied are superimposed. The striking features are: i) the frontal system formed by the 20°, 21°, 22° and 23° C isotherms extending from the southern tip of Lower (Baja) California roughly southwards for about 100 miles then turning westwards, eventually becoming weaker; fronts were found within this system; ii) the strong indication of upwelling inshore along the west coast of Lower California, with apparent southward transport of the upwelled water; iii) the intrusion of warm water (24, 25°, and 26° C isotherms) into the Gulf along its eastern side. This distribution of surface temperatures agrees qualitatively with those drawn from the data of Cal. C. O. F. I cruises 5604 and 5704 (both in April, like TO-60-1) and from the Vermilion Sea Expedition (April to May 1959). The configuration of the isotherms at the surface, on TO-60-1, persisted more or le

a depth of about 50 m, but became modified ow that depth. Most of the data of TO-60-1 e been processed and drawn, and form the is for some of the present discussion. For nomy of space such drawings have not been ared.

The isohalines agree qualitatively with the therms, confirming that the frontal system formed from warm, saline water to the east cool, less saline water to the west and thwest; the salinity contours also persist to east 50 m deep. Horizontal contours of st of the other properties substantiate this ture. Even so, vertical profiles, especially salinity, between stations 7 and 22, and 23 and show that the area is a very complicated one he upper 100 m.

Our investigation of fronts has been, then, study of very small sections of a rather ge frontal system; it is an assumption that at was found applies more or less to the ole system. Moreover, the sections studied e shown much more intense gradients than ear in Fig. 1, but this is certainly a function he density of observations in time and space.

### 3.2 The Fronts

Quite the best front, from the standpoint of anographic study, is that immediately off- re from Cape San Lucas (fronts 3 and 5, . 1). This is because the land protects the surface from the prevailing northwest winds ich would, and do out to sea, mix the surface ters. (Thermocline depth is much greater to sea than in the mouth of the Gulf). The ring has, for instance, made it rather hard to ide confidently what kinds of water formed nts 2 and 4. Front 1, judging from the perature regime (Fig. 1), was between up- lled water and non-upwelled water in the lifornia Current system.

Fig. 2 shows the distribution of surface therms as derived from the initial thermograph vey (19 to 20 April, 1961) of front 5. The h node ($T>23^{\circ}C$) to the north and east, and intrusion of cool water ($T<20^{\circ}C$) from the st, are the chief features; the front is formed ween the warm and the cool waters. This damental plan was still present five days er when a final thermograph survey (23 to 24 ril) was made (Fig. 3); the warm water had, wever, moved westwards inshore, while the ol water had moved eastwards offshore, the front being maintained between them (Fig. 3). Other fronts out to sea (1, 2 and 4) were much faster moving and less stable, and therefore harder to study.

Perhaps more gratifying than the stability of this front was its fundamental similarity to front 3 which was in the same area eleven months earlier (22 May, 1960). Fig. 4 shows the surface isotherms of front 3; the warm water west of the node ($T>25^{\circ}C$) appears to have moved westwards cutting across cool water coming from the north and separating a parcel of it to form an eddy south of the front roughly opposite the warm node. Such a situation could arise from that found at front 5, which makes us think that fronts 3 and 5 are basically alike. Unfortunately, circumstances did not allow us to study front 3 further.

The westward movement of warm water at front 5 was shown by four drogues, two with parachute at 5 m depth and two with them at 50 m. These were put into the water near the middle or slightly towards the warm side of the front on the afternoon of 21 April, about 12 mi southeast of Punta Palmilla. All were observed till lost: two, one of each kind, for about 39 hours, two for about 51 hours. The southernmost one (nearest the cool water) moved first a little northwest, then southeast, and finally north, before being lost. The other three all moved first north, then roughly west, in warm water. These drogue movements are clear evidence of the westward movement of warm water inshore.

A G.E.K (Geomagnetic ElectroKinetograph) survey was made at the northeastern part of front 5 where it bends from an east-west line to a north-south one (see Figs. 2 and 3), about 10 mi southeast of Punta Palmilla. This survey showed that warm (surface) water was moving roughly southwest at 10-30 cm/sec. Two observations (no. 4 and 9 in Table I), in the bend in the front, showed that cool water was moving slowly eastwards.

The indication by the G.E.K. of water moving out of the mouth of the Gulf is in full accord with the view of Roden and Groves (1959) that surface water generally leaves the Gulf on its western side. They state that maximum transport is at about 50 m depth.

Having established the orientation and movement of the front, we then investigated it at depth. Three BT (BathyThermograph) passes

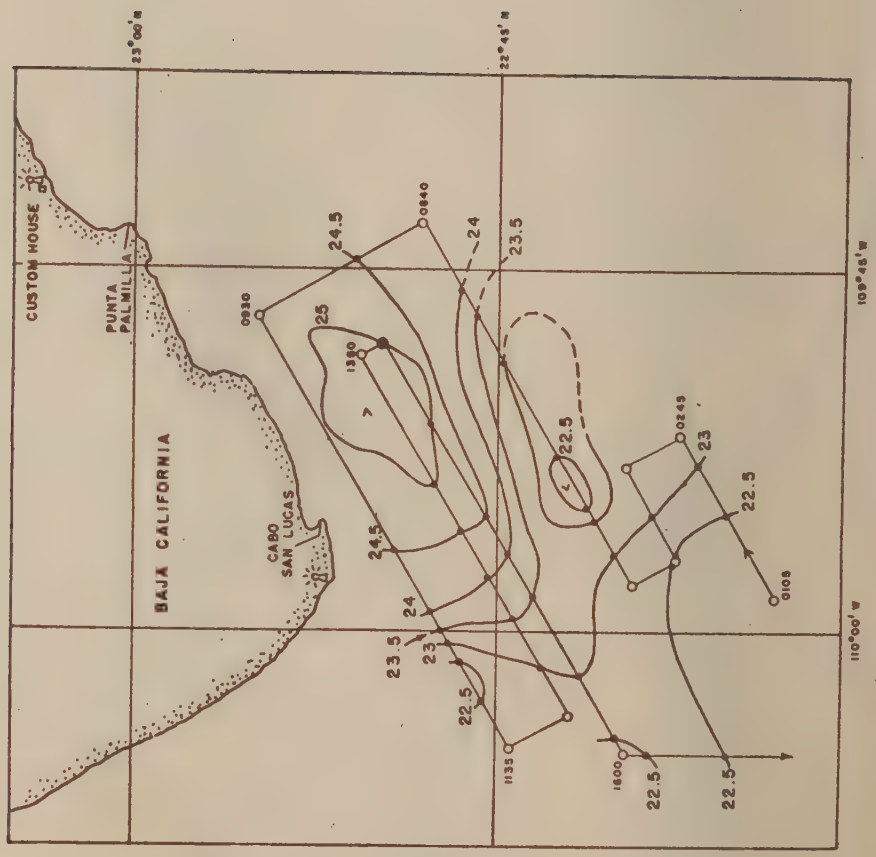


Fig. 4 Distribution of surface isotherms (°C) at front 3, off Cape San Lucas, Lower California, from a thermograph survey (0105 hrs - 1600 + hrs 22 May 1960), the track of which is shown.
--o-- time check; --•-- temperature check.

re made; a pass consisted of repeated rapid erings of a BT while the vessel moved slowly ough the front. A bucket-thermometer read- of the surface temperature and a sample of er, for salinity determination, were taken h each BT. These passes were made about mi southeast of Punta Palmilla.

Fig. 5 shows the temperature profile derived m one of the passes made at front 5. It does differ qualitatively from those of the other passes, but does encompass a somewhat ater range of surface temperature. The ef feature is the relatively complicated ucture at depth compared with that at the face. The warm water apparently intrudes the cool, while the cool may intrude into warm, complementarily (16°, 17°, 18° and C isotherms). The 21°, 22° and 23°C therms, by which the front is detected by the rmograph, do not contribute to the large ersions at mid-depths (20 - 70 m).

A similar BT pass made at front 2 also showed mperature structure at depth that was not ealed by observations at the surface. This p (35 - 55 m) structure took the form of a er of water of temperature about 20°C under- g surface water the temperature of which ged from about 19.9°C to about 21.7°C across front. This layer of water was interrupted ll three passes made there, being absent ectly beneath the middle of the front as erved at the surface. This structure could derived from that found at front 5, though does not mean that the front 5 situation ually existed at front 2. Nevertheless, there strong indication that similar processes occur at both fronts, though presumably with different intensities.

Cromwell and Reid (1956) use the term "frontal layer" to mean the highly stratified boundary between the two kinds of water forming the front; in the fronts they reported, this layer was inclined towards the surface and became more or less horizontal at some depth above the main thermocline. Thus, the front observed on the thermograph corresponds to where the frontal layer meets the sea surface. Evidently, the Cape San Lucas frontal system has a more complicated, but perhaps less well-defined, frontal layer than those they observed. The 16°, 17° 18° and 19°C isotherms (Fig. 5) are not close together in the zone of inversion, which suggests that mixing occurs there. The stippled areas, following the presentation of Cromwell and Reid, show water that is practically isothermal vertically. In the fronts they reported on there was little salinity gradient, in which case density was almost entirely determined by temperature; hence vertical mixing would require least energy where water was vertically isothermal. This is much less true of fronts, such as the one being discussed, where salinity is important in determining density. There are five main parcels of water that are vertically isothermal: one is the surface water, another is the deep water (below the 14°C isotherm); the other three correspond to the intrusion of warm water and to the cool water above and below this warm intrusion. The main thermocline is at about 70 m depth on the cool side, and at between 30 m and 50 m depth on the warm side. There is a shallow thermocline on the cool side, formed by the 18°, 19° and 20°C isotherms which constitute the intrusion

Table I

| of G.E.K. ervation | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| rent direction rue) | 203 | 209 | 215 | 077 | 215 | 215 | 228 | 219 | 044 |
| rent velocity /sec) | 11 | 19 | 3 | 16 | 11 | 30 | 22 | 26 | 4 |
| face temperature at t of observation (°C) 1/ | 22.5 w | 22.0 m | 21.0 c | 20.2 c | 22.0 m | 22.8 w | 22.3 w | 21.3 m | 21.0 c |

1/ For purposes of discussion, here and elsewhere, the surface temperature has been arbitrarily classified as warm (w) — > 22.0°C, middle (m) — 21.0° - 22.0°C, and cool (c) — < 21.0°C.

Fig. 5 The temperature profile ($^{o}$C) based on a BT pass (BT's Nos. 1 to 23)

of (probably) upwelled water from north of Cape Falso into the frontal area; these isotherms are shown in Fig. 2.

Fig. 6 shows the gradients of temperature (T), salinity (S), and thermosteric anomaly ($\delta_T$) across front 5 at the surface; the temperature readings were from the bucket thermometers, and the salinity from the water samples collected with each BT on pass no. 3; $\delta_T$ was computed from these contemporaneous values of temperature and salinity. The close agreement of the temperature and salinity gradients shows that the front was formed by warm (T~23°C), saline (S≥35.00°/oo) water to the east and north, and by cool (T~20.5°C), less saline (S~34.60°/oo) water to the west and south. Comparable values for front 2 are: 19.6°C - 34.32°/oo and 21.6°C - 34.72°/oo.

The temperature inversion at front 5, so obvious in Fig. 5 and the profiles based on the BT passes, appears in the temperature profile based on data from a triplet of 10-bottle hydrocasts to about 250 m depth; Station 5B1 on the warm side, 5B2 in the middle, and 5B3 on the cool side. The casts were made two days after the BT passes. In this profile, only the 17°C isotherm was inverted. Another triplet of similar casts (station 5E1 (w), 5E2 (m), and 5E3 (c) ), made a day after the first three, generated a profile lacking an inversion, though the 17°C isotherm was more than 10 m deeper at the middle station that at either lateral station. This apparent development, from the BT pass to the last triplet of hydrocasts, suggests that some mixing or redistribution of heat has taken place, but it should be noted that the three groups of observations were not all in exactly the same place, nor were they quite similarly related to the front at depth. They were all grouped in an area between latitudes 22°44' and 23° North, and longitudes 109°27' and 109°40' West. The profile based on the BT's taken for each hydrocast showed an inversion in the 17°C isotherm for the first triplet (B series) of casts, and in the 16°C isotherm for the second set (E series).

The salinity is the best indicator of the two kinds of water forming the front, judging from the salinity profiles of the two triplets of hydrocasts. All such profiles were drawn in the most objective way even though they were largely interpolated. All properties were drawn against the thermosteric anomaly first; isohalines were determined by the observations at the stations and by the intersections of specific isotherms and specific isosteres. The profiles of properties with depth were then derived from those of properties with thermosteric anomaly.

The detail imparted to the salinity profile by this method agrees strongly with the temperature structure seen on Fig. 5. Fig. 7 shows the salinity profile for the first triplet (B series) of hydrocasts. The 17°C isotherm from the corresponding temperature profile has been drawn on the salinity profile to show the close agreement between the cooler, lower salinity water and the warmer, higher salinity water. The salinity structure shown by the profile - complementary intrusions of the two kinds of water into each other - persisted almost unchanged till the later triplet (E series) of hydrocasts; the salinity profile of this later series (not given here) showed that the cooler, less saline water apparently moved farther into the warmer, more saline water, for it was observable as a pronounced salinity minimum at the "warm" station at about 30 m depth. The salinity-depth curves in Fig. 7 are based on the salinities observed and on those interpolated at standard depths. The curve for the warm side shows the marked influence of low-salinity water at about 30 m and 70 m depths; that is, above and below the prominent obtrusion of high-salinity water between 30 m and 70 m depths. The curve for the middle station shows that the two levels of salinity, characterizing the two types of water forming the front, are only mixed within a relatively narrow range of depth, because the curve is essentially like that of the cool side down to about 25 m depth and like that of the warm side from about 40 m to about 130 m where all three curves become practically the same. Above about 125 m these three curves resemble the T-S curves.

Although oxygen, nitrate-, and nitrite-nitrogen contents were measured for each cast-bottle sample their profiles do not throw much further light on the structure of the front. The oxygen profiles qualitatively resemble the corresponding temperature profiles, except that the oxygen profile of the first (B) series of casts lacks the inversion found in the 17°C isotherm in the B series temperature profile. The nitrite profiles showed maxima: at about 25 m on the warm side in the first series of casts; at about 30 m on the warm and cool sides of the second series, with a somewhat lower value in the middle. The maximum on the warm side in the first series is a little shallower than the salinity maximum, but corresponds fairly well with the sharp salinity gradient. The nitrate profiles show maxima at greater depths than

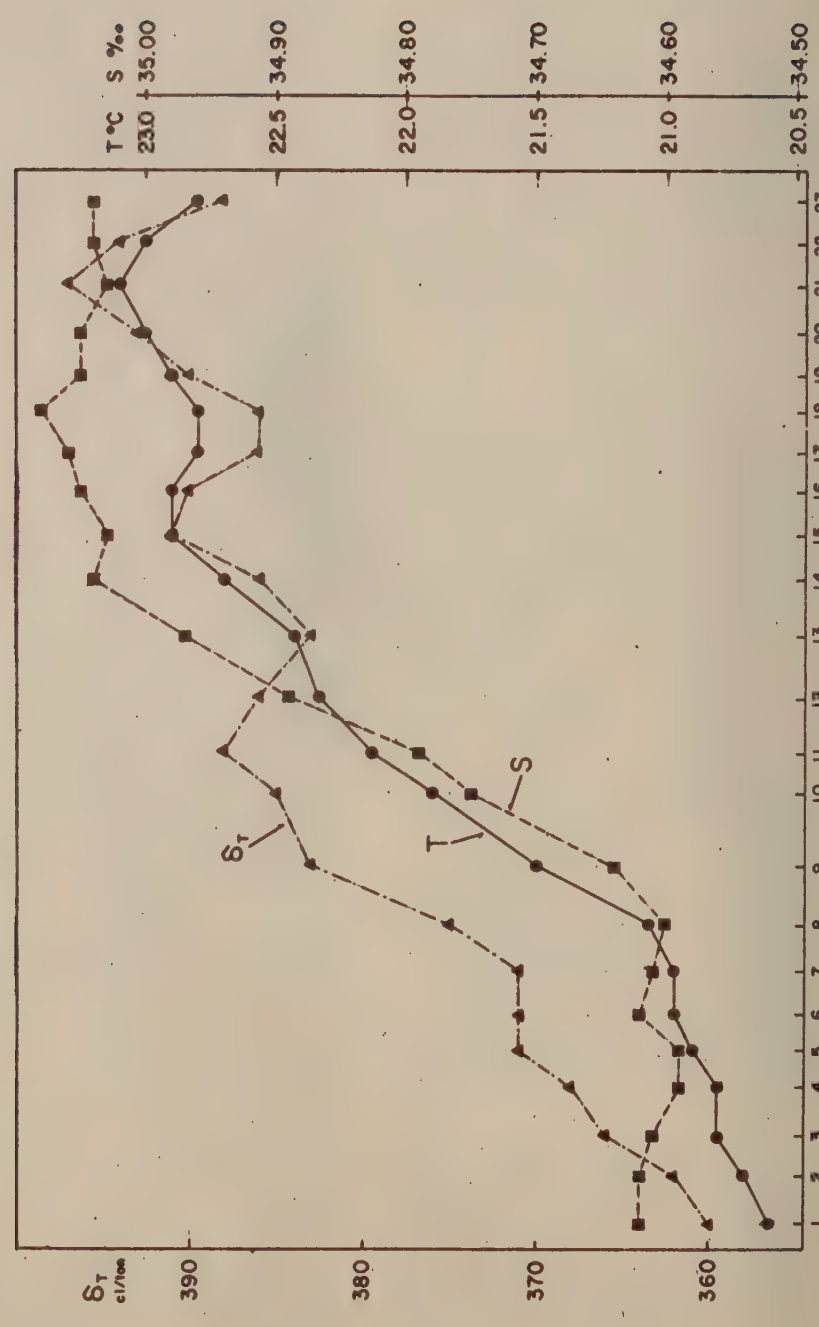


Fig. 6 Gradients of surface temperature (T), salinity (S), and thermosteric anomaly ($\delta$ T), across front 5, from observations made with each BT lowering on BT pass no. 3 (fig. 5).

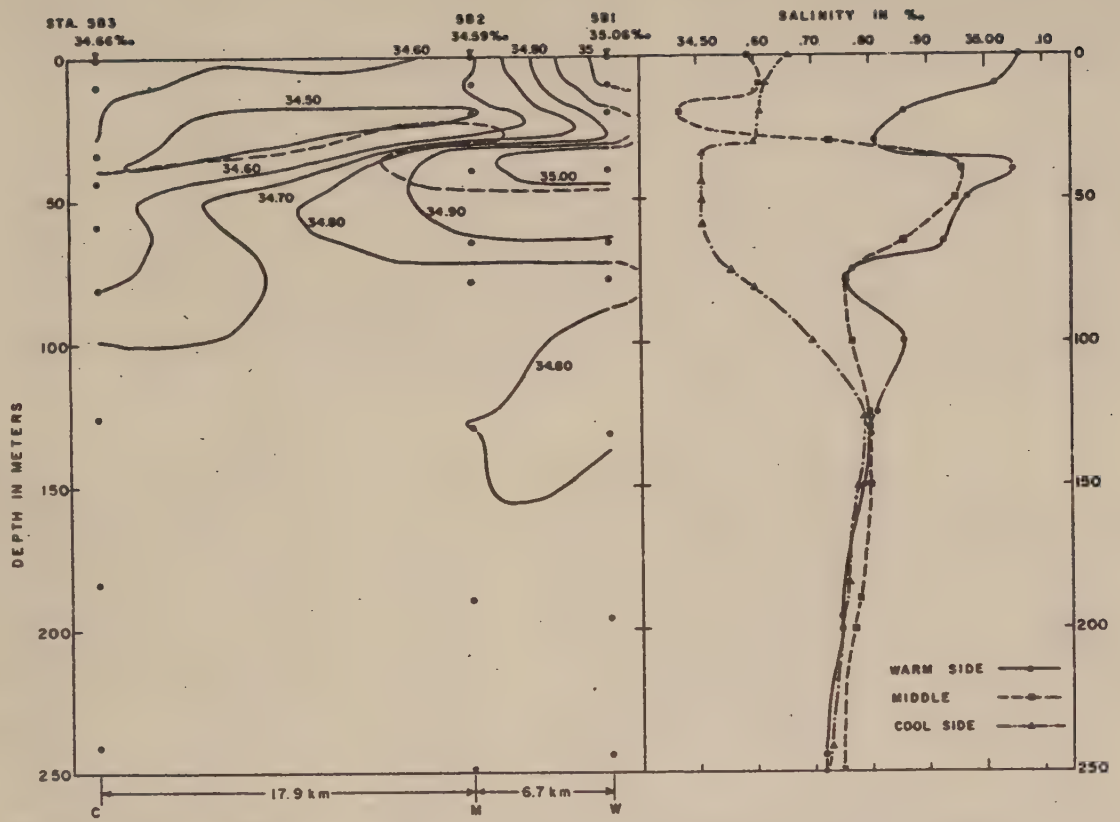


Fig. 7 The salinity profile and salinity-depth curves for the first (B) series of hydrocasts at front 5. Stations 5B1, 5B2, and 5B3 are on the warm side (w), in the middle (m), and on the cool side (c) of the front, respectively. The dotted contour is that of the 17°C. isotherm from the corresponding temperature profile, to show the relation of the temperature inversion to the salinity inversion.

those of the nitrate, as might be expected from the fact that nitrate succeeds nitrite in oxidative decay. The nitrate profiles also show other features that are not readily explained, but these are, conveniently, well below the frontal zone.

Most of the results from fronts 1, 2, and 4, besides being based on fewer and less coherent observations, do not permit any confident explanation. Apparently, Gulf water did not participate in them, unless it had been much modified. Even so, the most probable salinity structure that the data provide is not entirely different from that found at front 5. There was not, evidently, a simple interface between the warm and the cool water. The surface temperature difference across front 2 (10 May 1960) was similar to that across front 4 (23 May 1960), and the actual values were similar: front 2 - 19.96° to 21.74°C: front 4 - 19.34° to 21.00°C.

This was surprising, considering that these two fronts were about two weeks apart; they were in almost the same place, however. Their respective T-S curves, for warm and cool sides, showed that a significant amount of change had taken place during the two weeks. The composition of their plankton on either side had also changed significantly.

These fronts far offshore were also moving faster than did fronts 3 and 5 (at Cape San Lucas) which made study of them difficult. For this and other reasons they will not be further considered here.

The results of biological observations at front 5 do not show any clear-cut patterns. Time did not allow us to make the density of observations so essential to obtaining significant biological results. The chief point of interest is whether this front (5) aggregates biota. Some results suggest that it does, others do not.

A triplet of Van Dorn plastic samplers was made at almost the same time as the first (B) series of hydrocasts. To avoid significant time delays, each cast consisted of only four samplers at 0, 25, 40, and 100 m depths. Therefore, the profile based on them (Fig. 8) cannot be considered quite reliable, even though it shows a marked maximum at the middle station at 25 m. A special cast to determine beam transmission and chlorophyll a at each meter of depth was made in the middle of the front at station 5E2 (second series of hydrocasts); this showed that chlorophyll a concentration changed markedly with small changes in depth. Owing to this fact, there is the possibility that maxima, such as that found in the middle of the front, existed also on either side, but that the wide-spaced bottles failed to sample these.

As it stands, the profile shows that maxima existed at all three stations, with the greatest in the middle. There the chlorophyll a concentration was approximately twice as great as that in the maxima at either station to the side. The profile maximum (0.66 mg. C per $m^3$) coincided with the high-salinity (S~34.90°/oo) water (see Fig. 7).

The number of samplers per cast was minimized to ensure three things: i) that a cast started in the middle of the front, did in fact sample "middle" water (at this time the structure of the front (5) at depth was not known because no data had been worked up); ii) that there was no marked time lag between the sampling of the warm side and of the cool side; iii) that water filters were freed of earlier samples in time for later ones.

Similar practical considerations, especially the great importance of eliminating difference in starting times of productivity experiments, confined our observations of productivity to the surface water. It usually took at least half an hour to cross the front (at 9 kt), and incubation of samples should start as close to local apparent noon as possible, because incubation should be for half a solar day for optimum results. The productivity at the surface increased on passing from the warm side to the cool; the values were: 6.87, 11.88, and 16.38 mg. C/$m^2$/day.

These two groups of results (chlorophyll a) indicating aggregation of phytoplankton in the front, the other (surface productivity) indicating a trend from one side to the other, characterize the remaining biological results.

Table II summarizes the results of net hauls made at front 5. All hauls were made along an isotherm (warm, middle or cool). The isotherm was noted from the thermograph and the vessel was allowed to drift; it usually drifted along an isotherm and the direction was noted (if possible) and used for the tow. The thermograph was checked during the tow to ensure that the haul did not pass into a less desirable kind of water.

To determine whether the front was a focus of biota, ratios of standardized volumes from the

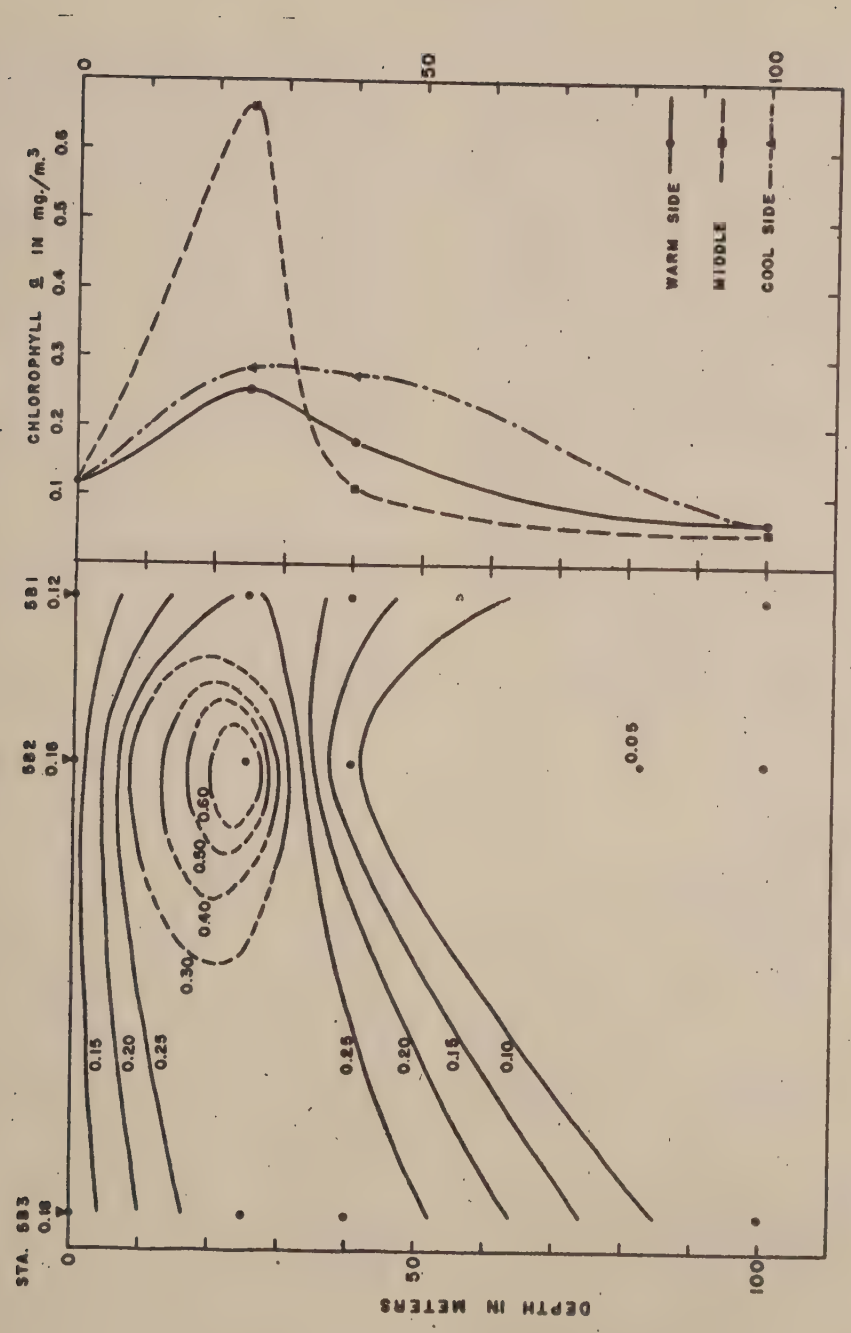


Fig. 8 The chlorophyll a profile and chlorophyll a - depth curves based on three Van Dorn plastic sampler casts at front 5. Stations 5B1, 5B2, and 5B3, correspond approximately to those on which the salinity profile (Fig. 7) was based.

haul to the next, across the front have been given (the volume for the warm side has been set at unity). It is assumed that if the front aggregates zooplankton, the volume in (the middle of) the front will be greater than that to either side. The sampling methods, which are quite standard, are open to criticism. The oblique hauls sample water below the frontal zone (depth>120 m). It is felt, however, that contributions from below the frontal zone are i) relatively independent of the front and not greater on one side than the other; ii) relatively small, because one set of hauls was taken at night when effects due to vertical migration would be minimal and the other was taken at dusk when these effects would be tending to a minimum (that is, the plankton would be mostly in the upper hundred meters). Most of the catch was, then, in the frontal zone and the relation of the catches to the front may indicate well enough the effect of the front on the biota. Another natural objection is that oblique hauls on either side of the front may sample parcels of water from the opposite side, by virtue of the Z-shaped interface (see Figs. 5 and 7). This is possible, but the data show that the cool side has a higher standing crop than the warm side; hence, if the haul on the warm side were sampling a significant amount of cool plankton-rich water, the observed differences would very likely be much less than they are.

From Table II we see that, according to the two sets of oblique hauls, the front aggregates zooplankton (ratios: 1.0 to 5.0 to 2.2; and 1.0 to 10.0 to 3.8). There is some suggestion that this is true of the Clarke-Bumpus samplers above the thermocline, but these nets sample so little water (about 70 $m^3$) that the differences are probably not reliable. These samplers were towed at three depths at a time on one wire; those below the thermocline failed in each haul.

Clarke-Bumpus samplers in the thermocline (bottom of mixed layer) show a trend of increasing volumes from the warm into the cool water.

The surface (horizontal) hauls also show increasing volumes towards the cool side, the ratios (1.0 to 3.4 to 8.7) being significant. Significance has not been tested statistically; the rough rule that differences of half or double a given value are significant, has been used. This rule, derived from studies by Winsor and Clarke (1940) and Silliman (1946), was based on counts and not volumes, but it is useful as a conservative rule-of-thumb.

Nekton-net hauls, the catch of which is largely micronekton (minimum linear dimen of 5 cm), show increasing values on passing from the cool to the warm side. It is suppo of course, that the nekton would not be direc (mechanically) aggregated by the front, thou it might accumulate there by preference; no that the micronekton components of the othe hauls have been given in Table II. The zoop component of the nekton hauls, mostly relati large euphausiids (about cm long), was much greater in the middle and on the cool side of front. This element of the biota was not apparently caught by any of the nets except t big nekton net which samples only to a depth 115 m at the most (Blackburn and associates

Aliquots of each sample were sorted an numbers of the predominant groups counted; volumes of the most abundant of these group measured by the method of Yentsch and Heba (1957). Table III shows the ratios of counts (t dardized to the full sample and to $10^3$ $m^3$ of strained), for qualitative comparison with vo ratios given in Table II. The following ratio of particular interest: i) those showing much values in the middle of the front - euphausiids both series (A and F) of oblique hauls, ptero the first (A) series of oblique hauls (the seco had a large number only on the cool side), cc and chaetognaths in the second (F) series of hauls and the Clarke-Bumpus hauls above th thermocline; ii) those showing much higher values on the cool side only - copepods, euphu pteropods and chaetognaths in the surface (D) of hauls, fish and stomatopod larvae in the (D) hauls; iii) those showing much higher val on the warm side - red crab larvae in the Cl Bumpus hauls in the thermocline, red crab a and prawns (shrimps?) in the nekton hauls; iv) those showing very low values in the mid chaetognaths in the Clarke-Bumpus haul in th thermocline; v) those showing high values o cool side and in the middle - euphausiids in t nekton (D) hauls. These results will not be analyzed further in this paper. The use of indicator organisms to determine water mas awaits further study, but should prove most ful. Evidently, some groups are consideraly more abundant than others, in relation to the and it is doubtful that even accidents of samp can account for this. Nevertheless, no cons pattern is evident, and much more sampling needed to determine with certainty whether t (convergent) front physically aggregates the Another difficulty, which might be diminishe by

Results of net hauls made at the Cape San Lucas Front (front 5)

| Station | Time of day | Depth of tow | Vol. plankton per $10^3 m^3$ | Ratio of volumes | Vol. micronekton[3] per $10^3 m^3$ | Ratio of volumes | Dominant forms: Zooplankton (by vol.&/or number) | Micronekton[3] |
|---|---|---|---|---|---|---|---|---|
| OBLIQUE 1m NET HAULS | | | | | | | | |
| 5A1 (w)[1] | n[2] | 300 | 20 | 1 | 95 | 1 | copepods, chaetognaths, ostracods | red crabs |
| 5A2 (m)[1] | n | 261 | 101 | 5.0 | 3 | 0.03 | copepods, euphausiids, pteropods | |
| 5A3 (c)[1] | n | 329 | 43 | 2.2 | 158 | 1.7 | copepods, pteropods, euphausiids, ostracods | red crabs |
| 5F1 (w) | d[2] | 200 | 20 | 1 | 120 | 1 | copepods, chaetognaths | red crabs |
| 5F2 (m) | d | 170 | 199 | 10.0 | 1638 | 13.7 | euphausiids, copepods | red crabs |
| 5F3 (c) | d | 321 | 75 | 3.8 | 12 | 0.1 | copepods, chaetognaths, pteropods, siphonophores | red crabs |
| HORIZONTAL 1m NET HAULS | | | | | | | | |
| 5D2 (w) | n | 3 | 52 | 1 | 46 | 1 | copepods, chaetognaths, pteropods | a large salp |
| 5D3 (m) | n | 3 | 179 | 3.4 | 0 | - | chaetognaths, copepods, pteropods, siphonophores | |
| 5D1 (c) | n | 3 | 452 | 8.7 | 52 | 1.1 | copepods, pteropods, siphonophores | salps |
| HORIZONTAL CLARKE-BUMPUS NET HAULS | | | | | | | | |
| i) ABOVE the thermocline | | | | | | | | |
| 5C1 (w) | d | 15 | 7 | 1 | 0 | - | copepods, chaetognaths, pteropods | |
| 5C2 (m) | d | 20 | 78 | 11.1 | 0 | - | chaetognaths, copepods | |
| 5C3 (c) | d | 15 | 58 | 8.3 | 0 | - | euphausiids, copepods, siphonophores | |
| ii) IN the thermocline | | | | | | | | |
| 5C1 (w) | d | 40 | 59 | 1 | 0 | - | red crab larvae, chaetognaths, copepods | |
| 5C2 (m) | d | 35 | 63 | 1.1 | 0 | - | euphausiids, red crab larvae, copepods | |
| 5C3 (c) | d | 25 | 127 | 2.2 | 0 | - | euphausiids, copepods, chaetognaths | |
| OBLIQUE 5ft x 5ft NEKTON NET HAULS | | | | | | | | |
| 5D2 (w) | n | 100 | 0.1 | 1 | 66 | 1 | | red crabs, fish, prawns |
| 5D3 (m) | n | 100 | 5 | 50 | 9 | 0.14 | euphausiids | red crabs, fish |
| 5D1 (c) | n | 100 | 5 | 50 | 8 | 0.12 | euphausiids, stomatopod larvae | fish |

1/ See Table I.
2/ n = night; d = dusk.
3/ Micronekton is, roughly speaking, a small organism of minimum linear dimension 5 cm. and of maximum linear dimension of, say, 15 cm.

Table III

Ratios of major groups of organisms in the net hauls made on the warm side, in the middle, and on the cool side of the Cape San Lucas Front (front 5). The ratios are of the counts, and the count of the warm side is set at unity. Ratios are only given when a group was represented in all catches of a triplet.

OBLIQUE HAULS.

| Organisms | Sta. 5A1 (w) | 5A2 (m) | 5A3 (c) | Sta. 5F1 (w) | 5F2 (m) | 5F3 (c) |
|---|---|---|---|---|---|---|
| Copepods | 1.0 | 1.7 | 0.8 | 1.0 | 5.6 | 2.2 |
| Euphausiids | 1.0 | 7.9 | 4.0 | 1.0 | 11.0 | 2.5 |
| Pteropods | 1.0 | 24.7 | 11.6 | - | - | - |
| Ostracods | 1.0 | 1.2 | 0.9 | - | - | - |
| Chaetognaths | 1.0 | 0.5 | 0.4 | 1.0 | 4.5 | 2.6 |
| Average | 1.0 | 2.3 | 1.2 | 1.0 | 7.2 | 2.4 |
| Total plankton volumes | 1.0 | 5.0 | 2.2 | 1.0 | 10.0 | 3.8 |

HORIZONTAL HAULS

i) SURFACE

| Organisms | Sta. 5D2 (w) | 5D3 (m) | 5D1 (c) |
|---|---|---|---|
| Copepods | 1.0 | 1.4 | 6.1 |
| Euphausiids | 1.0 | 2.1 | 5.2 |
| Pteropods | 1.0 | 3.2 | 27.0 |
| Chaetognaths | 1.0 | 1.8 | 1.6 |
| Siphonophores | 1.0 | 2.1 | 4.9 |
| Average | 1.0 | 2.1 | 9.0 |
| Total plankton volumes | 1.0 | 3.4 | 8.7 |

ii) CLARKE-BUMPUS: a) ABOVE thermocline

| Sta. | 5C1 (w) | 5C2 (m) | 5C3 (c) |
|---|---|---|---|
| | 1.0 | 6.0 | 1.2 |
| | - | - | - |
| | - | - | - |
| | 1.4 | 14.0 | 1.1 |
| | - | - | - |
| | 1.0 | 10.0 | 1.1 |
| | 1.0 | 11.1 | 8.3 |

b) IN thermocline

| | | | |
|---|---|---|---|
| Copepods | 1.0 | 0.8 | 1.8 |
| Red crab larvae | 1.0 | 0.5 | ~0 |
| Chaetognaths | 1.0 | 0.1 | 0.8 |
| Average | 1.0 | 0.5 | 0.9 |
| Total plankton volumes | 1.0 | 1.1 | 2.2 |

OBLIQUE HAULS

NEKTON

| Sta. | 5D2 (w) | 5D3 (m) | 5D1 (c) | |
|---|---|---|---|---|
| Red crab adults | 1.0 | 0.04 | ~0 | |
| Prawns | 1.0 | 0.08 | - | |
| Fish | 1.0 | 0.3 | 4.0 | |
| Leptocephalus | 1.0 | 1.2 | 1.8 | |
| Squid | 1.0 | 3.0 | 2.7 | |
| Euphausiids | 1.0 | 73.2 | 64.8 | } plankton |
| Stomatopod larvae | 1.0 | 0.8 | 11.3 | } plankton |
| Average | 1.0 | 11.2 | 12.1 | |
| Total volumes | 1.0 | 0.2 | 0.2 | |

ıer close inspection of the data to hand, is
of grazing; the rate may well be different
e middle from what it is on either side,
could affect the results of net hauls
ificantly. My tentative view, however, is
aggregation here is more likely to occur
not, but may well be masked to some
nt by the relatively greater contribution of
-water biota at this time (spring, the up-
ing season) of the year. The standing crop
oplankton at front 2 was about three times
ıter on the cool side than on the warm; the
es were roughly the same on either side of
t 4, however.

Front 5, as noted earlier, was not visible
ıe sea surface, and although the sea state
ıged from calm to choppy as the vessel
ed offshore from the lee of the land mass,
fairly rapid change was not related, directly
ast, to the front. The front was therefore in calm waters, and, in these, marlin were especially abundant. A few small sport-fishing boats had successful fishing while we were there. Birds were not particularly abundant.

No tuna or tuna-fishing vessels were sighted during the work at front 5 (19-24 April, 1961); a few schools of tuna (species unindentified) were sighted near the Tres Marias Islands on cruise TO-60-1 (May 1960), but no tuna-boats were seen. Fig. 9 and 10 show the distribution of catch (of yellowfin) and effort by purse-seiners in and near the Gulf entrance in May 1960 and April 1961, respectively, corresponding to the months of the cruises TO-60-1 and TO-61-1. The data were kindly supplied by the Inter-American Tropical Tuna Commission. No conclusions are drawn from these two Figures at present, but a comparison of Figures 1 and 9 is of interest.

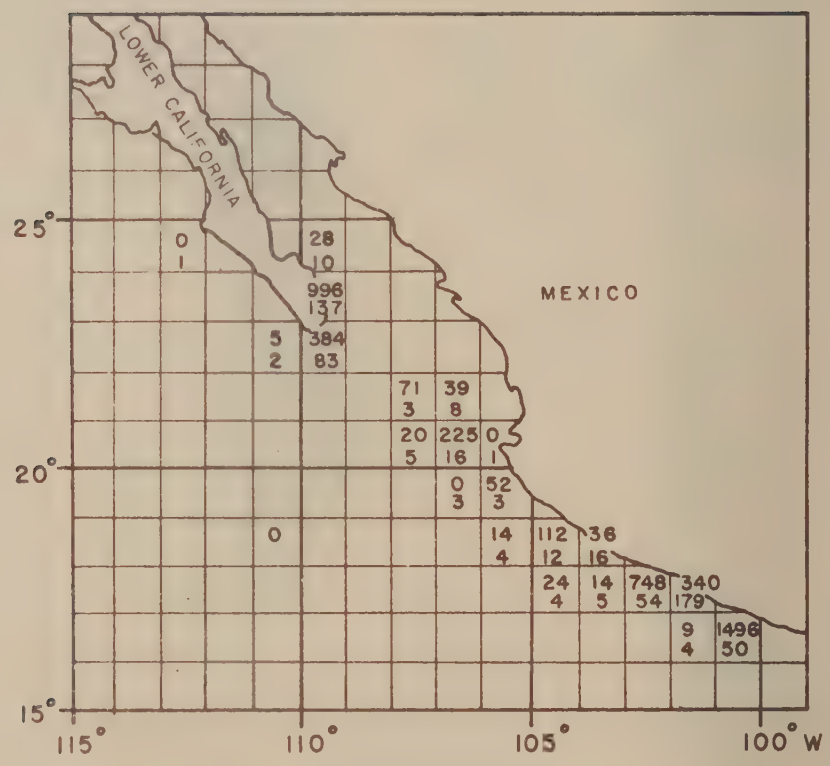


Fig. 9 Distribution of effort by purse-seiners and their catch of yellowfin, in May 1960, by one-degree squares, off western Mexico and Lowe California. The upper figure in each square is the catch in tons, the lower figure is the corresponding effort in standardized boat-da

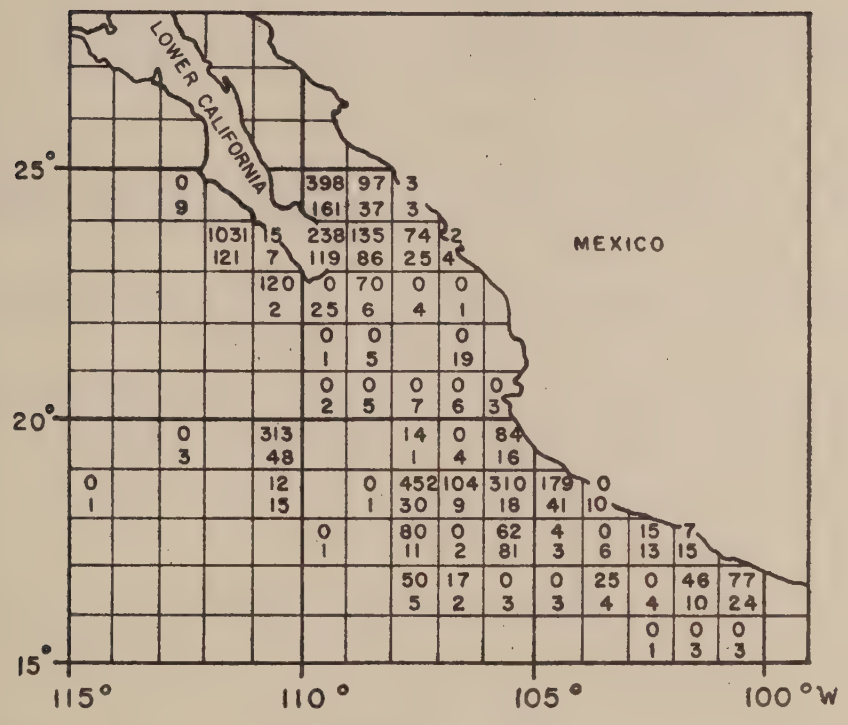


Fig. 10 Distribution of effort by purse-seiners and their catch of yellowfin, in April 1961, by one-degree squares, off western Mexico and Lower California. Upper figure in each square is the catch in tons, the lower figure is the corresponding effort in standardized boat-days.

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# 24.

# Problems in Tagging Salmon at Sea

By

ALLAN C. HARTT*

Tagging has become a standard and useful tool in the research and management of salmon in coastal areas as a result of many years' development of methods and techniques. In extending salmon tagging to the high seas, however, we have encountered new problems that require considerable modification of methods used in coastal areas. It is the purpose of this paper to describe some of the problems met in oceanic salmon tagging, and to report progress in overcoming them.

Although the experiments discussed were entirely with Pacific salmon (genus *Oncorhynchus*) and steelhead trout (genus *Salmo*), findings should be applicable in some measure to Atlantic salmon (genus *Salmo*) and perhaps to other pelagic species.

Data discussed are from United States high seas tagging experiments conducted from 1955 through 1960 under auspices of the International North Pacific Fisheries Commission (Canada, Japan, and United States).** Tagging is one of several major investigations by the three countries to determine oceanic distribution and movements of salmon with reference to continent of origin. This information is needed for determining a line or lines at sea which best separate Asian and American salmon in accordance with terms of the North Pacific Fisheries Convention (INPFC Annual Report for year 1959). Summaries of progress in the various research programs are available in INPFC Annual Reports (INPFC 1956—1960). In addition, a detailed report on fishing gear used, methods and tagging results of United States experiments for the years 1956—1958 has been published (Hartt, 1962). The present paper draws together our findings regarding gear and methods for the full six years of operations, 1955—1960.

## Fishing Gear

The selection of gear for catching salmon for tagging purposes is a much more important consideration in high seas than in coastal experiments. This is due mainly to the prevalence of rough water, and to the more delicate condition of salmon during their ocean feeding period. Salmon at sea have a relatively thin mucous layer and skin, and are easily scaled. As a result, the success of tag return varies greatly according to the degree of injury caused by the gear.

The four types of gear commonly used for taking salmon at sea are gill nets, long lines, purse seines, and trolls. Trolling will not be discussed, since this gear has not been used in the mid-Pacific experiments. (The mortality of troll-caught chinook salmon (*O. tshawytscha*) is discussed by Parker and Black (1959).) Sufficient numbers of tagged salmon have been released from the other types of gear that the problems of injury may be discussed, and the relative success of tag return compared.

### Gill nets

Since gill nets are effective and convenient for taking salmon at sea, it would be very desirable if they could be used for taking salmon for tagging. However, tag returns have been consistently poor in all high seas experiments where this gear has been employed.

In 1955, tagging experiments in the Gulf of Alaska using gill nets for capturing specimens yielded only three returns from 333 salmon released, or less than 1.0%. These were experiments only incidental to the main task of exploratory fishing by the "John N. Cobb" that year (Powell and Peterson, 1957), but the very low rate of return indicates the difficulty in releasing fish in good condition when caught by gill nets. Japanese biologists released many salmon from gill nets annually between 1952 and 1956 in the North Pacific and Bering Sea. Returns were less than 1% each year. Their results were better in 1957, when 13 returns (2.1%) were received from 621 tagged red salmon (*O. nerka*) released (Japan, Fisheries Agency, 1958). For comparison, red salmon released from purse seines in the same vicinity in 1957 yielded 57 returns from 729 tagged, or 7.8%.

In coastal areas, salmon have been successfully tagged from gill nets by constantly tending a short section of net and removing the fish to a holding net as soon as possible after gilling. In experiments in Bristol Bay in 1950, for example, 41% of those tagged from gill nets in the above manner were returned (1754 released, 722 returned; unpublished data,

* Fisheries Research Institute, College of Fisheries, University of Washington, Seattle.

** Contribution No. 126, College of Fisheries, University of Washington.

Tagging by the United States section of the INPFC has been done by the F.R.I. (College of Fisheries, University of Washington) under contract from the United States Fish and Wildlife Service, Bureau of Commercial Fisheries.

heries Research Institute Bristol Bay project, 1950). these experiments, fish injured or obviously kened by their struggles in the gill net were not ged. Moreover, their recapture was only a few rs or days after release, whereas maturing salmon ged at sea are usually at liberty three weeks or ger. In high seas tagging from gill nets, it is not ctical to use the methods described for coastal as. Since fish are usually scattered, a very long gill must be used to take reasonable numbers, and time in the net correspondingly increases. More-, the prevalent chop and swell do considerable itional damage. In most high seas tagging from nets it has not been practical to patrol the net a smaller boat, so the net is simply set for the red period of time, and then retrieved in the al manner; fish in apparently good condition are oved carefully and either tagged and released ctly or placed in a holding tank and tagged later. n those in relatively "good" condition must suffer igh mortality, as evidenced by the low rates of rn cited. Thus, gill nets, although an effective ns of capturing salmon, are not a practical gear agging on the high seas.

### g lines

he Japanese, who for many years have fished ion commercially with long lines, have since been very successful in tagging salmon caught by means in the central North Pacific and Bering The gear consists of a light cotton or synthetic n line suspended near the surface by small floats. nofilament nylon "branch lines" or gangions ut one meter long are spaced every 3 meters. ks are baited with whole small fish. The gear rs from Danish long lines as described by Larsen 0) in having shorter gangions and thereby er spacing of hooks, and also in the elimination inkers. Several miles of the gear are set during hours of darkness or early morning. Fish are ed immediately as they are brought aboard.By ing only lively fish with superficial hook injuries, returns have been much greater than in experi-ts where gill nets were used. In 1958 for example, reds were returned from 1137 mixed mature immature reds released, or 9.2% (INPFC ual Report for 1958). Of 250 maturing red ion similarly tagged and released in the eastern ng Sea, 25 — 29 June 1960, 50 were returned, 0.0%. By way of comparison, 213 purse-seine-ght reds released in the same general vicinity on nd 21 June 1960, yielded 90 returns, or 41.8%. return percentages were higher from both types ear in 1960, partly because of general improve-t of techniques, and partly because of a $ 25.00 reward offered by the United States for the return of high seas tags captured by our fishermen (irrespective of country releasing fish).

### Purse seines

Following trials with gill nets in early 1956, purse seines have been used by the Fisheries Research Institute in all high seas salmon tagging experiments. Salmon caught for tagging by purse-seines have consistently yielded a higher tag return rate than those caught by either gill nets or long lines, where comparable data were available. Each year the gear has been improved or methods of fishing adapted in order to make fishing more effective or to reduce injury by the gear.

The small-sized salmon encountered at sea were found to gill in the web of standard commercial purse seines ($4^1/_4$" mesh), so that very small mesh size (2") was required to avoid gilling of the smallest fish. The heavier knotted netting in the bunt end of the seine was found to chafe and scale fish severely during brailing, and small-meshed knotless webbing was therefore used to reduce this problem. Also, an outrigger pole with a bridle attached to the bunt was used to hold the bunt from collapsing against the side of the vessel as the seine set was completed. This insured swimming room for the fish during the critical last few minutes of retrieving the web, when collapsing of the net due to wind and seas previously caused considerable injury. Figures 1 and 2 illustrate the outrigger and bridle just before, and just after, completion of web retrieve. Figure 3 shows fish in the bunt, and the ample swimming room afforded by the outrigger and bridle.

In the instance illustrated in Figures 1—3, seas are calm. When chop and swell are large, fish must be removed quickly to the holding tank, or chafing injury would result even using the knotless bunt material.

From the foregoing, it is evident that purse seines can provide fish in excellent condition for tagging at sea. However, on the debit side, seine gear cannot be used in as rough weather as can gill nets or long lines. The large size (400 fathoms long, 35 fathoms deep) and weight of the seines place an extreme strain on the ship's tackle in heavy chop and swell. The exact conditions under which fishing can be done would be hard to define, since it depends on the direction the seine is to be set in respect to wind direction, and also upon the type of swell, whether short and steep or long and rounded. The weather limitations to seining at sea are probably not a serious handicap in our operations however, since only a small percentage of salmon caught by any type of gear in rough seas would be in suitable condition for tagging.

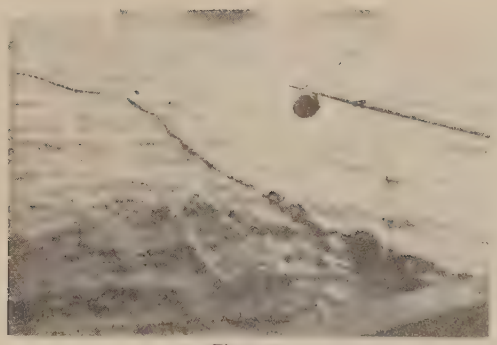

Figure 1

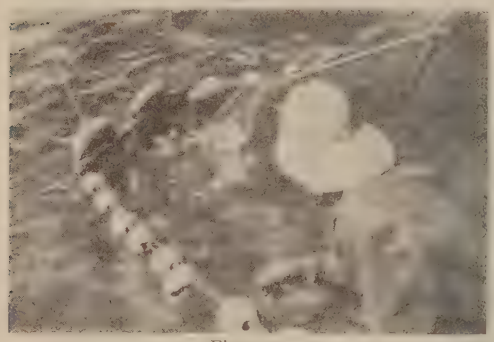

Figure 2

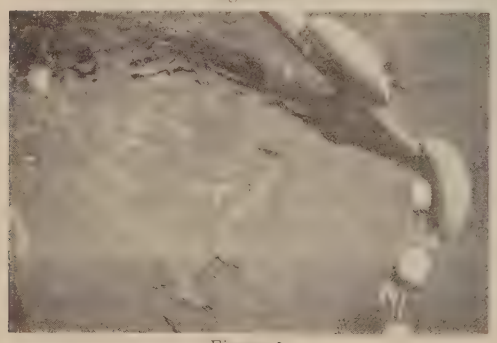

Figure 3

Figure 4

Figures 1—4. 1: Outrigger and bridle in position just before last of web is retrieved; 2: Bridle holding bunt open during brailing; 3: Behaviour of fish in open bunt; 4: Brailing from bunt to holding tank.

Even within the range of weather conditions under which seines can be fished, the success of return is reduced when rough seas cause appreciable injury. Table 1 illustrates the success of return of red salmon tagged south of Adak, according to their general condition at release. The 82 fish released on 5 June 1960 classified as "poor" yielded only 1.2% return as compared to at least 9.0% return for comparable groups classified as "good". The condition referred to is based primarily on the degree of scaling since this is an index of the amount of chafing injury by the web. The example shown is an extreme case, since in addition to very heavy swell and chop, there were mechanical difficulties in completing the haul, which allowed the web to confine the fish and delayed brailing. Results illustrate the seriousness of gear injury, however, and the importance of improving methods and gear to minimize such injury.

**Table 1**

**Numbers of tagged red salmon released and returned, according to general condition of fish at release**

(3 days' operations south of Adak Island, 1960, vessel "Renown")

| Date of Release | Number Released | Number Returned | Percent Returned | General Condition of Fish |
|---|---|---|---|---|
| 5 June ..... | 82 | 1 | 1.2 | Poor |
| 6 June ..... | 155 | 14 | 9.0 | Good |
| 7 June ..... | 110 | 10 | 9.1 | Good |

In comparing the several types of gear for taking salmon at sea, seines have shown an unexpected advantage over gill nets or long lines in that the direction of fish movement at time of catch is indicated by the direction of set of the seine. Seines are set in a semi-circle and held open for approximately 30 minutes, thus catching salmon moving generally toward the opening of the net. By observations of results of repeated sets in several directions it has been found that salmon move in very definite and consistent patterns in some areas at sea. In five seasons' operations in the area south of Adak Island, for instance, 185 sets with the seine open toward the east averaged 142 salmon, while 31 sets open west yielded an average of only 9 salmon. Thus in interpreting tag results, direction of movement at time of release is known as well as subsequent movement toward point of recapture. Under ideal conditions gill nets also may indicate approximate direction of movement of fish caught, by observing the relative numbers of fish gilling from each side of the net. When wind or tide shifts the direction of the lie of the gill net, such information is lost.

Gear selectivity is another important problem in catching salmon for tagging, and is probably more

ronounced at sea than in coastal areas. Of the 3 pes of gear discussed, the purse seine probably kes a more representative cross-section of species id sizes, since mesh size is small enough to retain e smallest fish and the depth of fishing is considerbly greater than the standard surface gill nets and ng lines being used at present. Canadian workers ive experimented with gill nets at various levels a depth of 200 feet in the Gulf of Alaska, and ive shown salmon present as deep as 160 to 200 feet ring the daytime, and as deep as 120 to 160 feet night (Neave, 1960). Since Neave showed a nsiderable decrease in numbers of fish at the eater depths, it is probable that the 210-foot depth the seines used by the United States is sufficient to ach the great majority of feeding salmon. The 210-ot depth is the measured depth while the net is in wing position and collecting fish.

Finally, in evaluating gear for tagging purposes, the e of catch or gear efficiency should be mentioned. Gill nets or long lines several miles long, and being fished for 4 to 8 hours, are undoubtedly more efficient in areas where salmon are few and scattered. Since a purse seine set requires about 2 hours and causes much wear and tear on a very heavy piece of gear, it is not practical to seine where fish are scarce. However, many areas have been found at sea where salmon are present in satisfactory numbers for seining. By seeking such areas, seiners have averaged 80 to 100 salmon per set, with some hauls netting over 1000. In this manner the more important concentrations of fish are tagged and released which is desirable at this stage of our knowledge.

### Holding Tanks

Live tanks as pictured in Fig. 5 have been used aboard the tagging vessels since 1956. Little or no scaling injury is caused after fish are placed in the tanks, regardless of weather conditions, and fish are

Figure 5. Tagging operations aboard vessel *Commander*, showing holding tanks and disposition of personnel.

in a convenient location for dipping and tagging. Since tag returns from seine-caught tank-held fish have been better than from gill net- or longline-caught fish, it has been assumed that the tank itself causes no appreciable mortality. However, it has been noticed that in large catches the success of return was usually poorer than in average or small catches, and further, that in some large samples, rate of return declined among the later fish released. The overall reduced return was thought to be due to injury previously sustained in the net due to the press of numbers, and to the additional time taken to brail large catches. The poorer return from the later fish released was thought to be due to fish in poorer condition remaining near the bottom of the tank, thus being among the last released.

In 1960, it was obvious in analyzing results of a series of directly comparable experiments, that not only was there a decline in percent return with time spent in the tanks, but also salmon held in the tank on the port side yielded much better returns than those held in the starboard tank. The decline in success of return with time spent in the tanks had been noted in previous years, but an example from our 1960 data will be cited since data may be shown also for the individual tanks. Earlier no record was kept of which tank the fish came from. In set No. C52 on 17 June, 536 salmon of mixed species were released. This required approximately $2^1/_2$ hours tagging from each tank. Table 2 shows the percent return by hour of tagging for the red salmon contained in this catch. Red salmon results were chosen because the percent return was much higher for this species. From both tanks there was a sharp reduction in the rate of return from the second and third hours' operations. The third hour's results might have shown a further decline had there been sufficient fish to require a full hour's tagging. (It should be explained that the 100 reds occurring in the first hour's tagging in the port tank was due to selection by the man dipping. This should not bias results but it greatly reduced numbers of reds released in the second and third hour's tagging in this tank.) Thus is illustrated the adverse effect of length of time spent in the tanks, and also the poorer rate of return from the starboard tank at least during the first hour.

For a more convincing illustration of the disparity between tanks in rate of return, Table 3 shows that 7 samples from the port tank yielded an average return of 36.3% while simultaneous releases from the starboard tank yielded only 21.7%. In all but one case (16 June) the port tank yielded consistently higher returns. The reason for the reversal on 16 June

**Table 2**

**Rate of return of tagged red salmon according to length of time in two holding tanks**

(Set C 52, 17 June 1960, near Umnak Island)

| | Port tank | | Starboard tank | |
|---|---|---|---|---|
| No. released 1st hour ..... | 100 | | 40 | |
| No. returned ..... | 36 | | 8 | |
| Percent returned ..... | | 36 | | 20.0 |
| No. released 2nd hour .... | 14 | | 42 | |
| No. returned ..... | 2 | | 5 | |
| Percent returned ..... | | 14.3 | | 11.9 |
| No. released 3rd hour ($^1/_2$ hour) ..... | 8 | | 34 | |
| No. returned ..... | 1 | | 4 | |
| Percent returned ..... | | 12.5 | | 11.8 |

**Table 3**

**Percent returns of tagged mature red salmon released from port and starboard holding tanks on vessel "Commander", 1960**

| Date Released | Set No. | Total released (all sp.) | Port tank | | | Starboard tank | | | Difference in percent return (Port-Starboard) |
|---|---|---|---|---|---|---|---|---|---|
| | | | No. Reds released (1st hr. only) | No. returned | Percent returned | No. Reds released (1st hr. only) | No. returned | Percent returned | |
| 9 June ..... | C42 | 296 | 83 | 27 | 32.5 | 66 | 10 | 15.2 | 17.3 |
| 10 June ..... | C43 | 253 | 69 | 23 | 33.3 | 48 | 9 | 18.8 | 14.5 |
| 10 June ..... | C45 | 176 | 82 | 27 | 32.9 | 50 | 8 | 16.0 | 16.9 |
| 16 June ..... | C49 | 216 | 77 | 22 | 28.6 | 43 | 13 | 30.2 | — 1.6 |
| 17 June ..... | C51 | 188 | 63 | 27 | 42.9 | 31 | 6 | 19.4 | 23.5 |
| 17 June ..... | C52 | 536 | 100 | 36 | 36.0 | 40 | 8 | 20.0 | 16.0 |
| 21 June ..... | C58 | 158 | 46 | 27 | 58.7 | 44 | 16 | 36.4 | 22.3 |
| | | Total | 520 | 189 | 36.3 | 322 | 70 | 21.7 | $\bar{x} = 15.6$ |

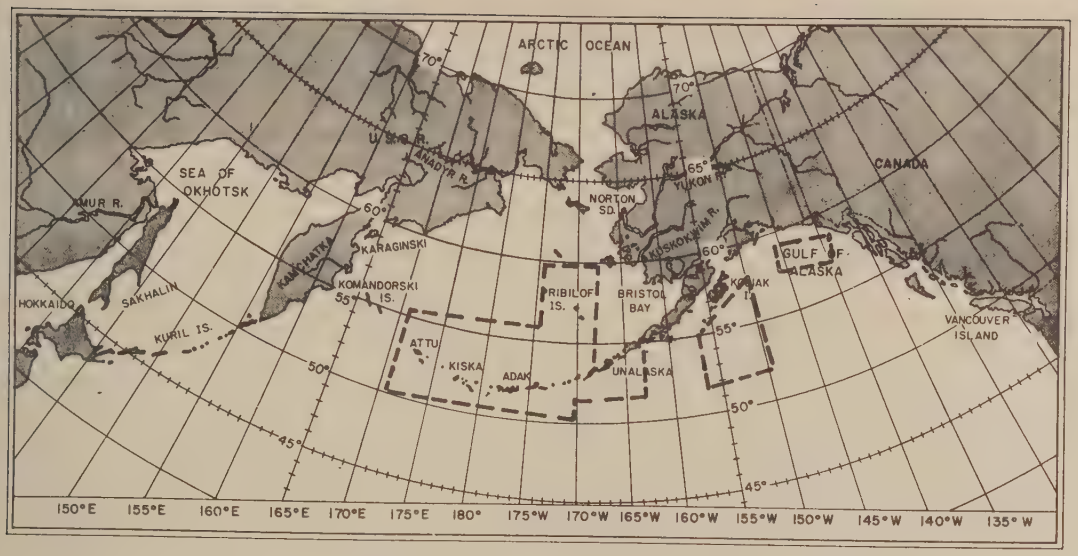


Figure 6. Areas of United States high seas salmon tagging operations, 1956—1960.

is unknown. Nevertheless the 15.6% advantage enjoyed by the port tank is strongly significant. A t-test indicates less than 0.01 probability that the true mean of the difference in return rate between tanks is zero. The 7 samples were released near the Aleutian Islands between 168° and 173° W (Fig. 6), and all were returned in Bristol Bay approximately 600 miles distant. Time at liberty was 20 to 50 days.

Faced with such an obvious defect in our gear or methods, we have recently reviewed the physical properties of the tanks, and water supplies, as well as details of fish handling and tagging personnel which might be causing the mortality. This, plus a preliminary investigation of literature on the subject strongly suggests that the trouble is due to an excess of dissolved air in the water supply, and possibly also to air bubbles and/or turbulence in the starboard, or inflow tank.

The following description of the water supply, tanks, and tagging procedures will assist in explaining the probable source of mortality.

The water supply on both the "Renown" and "Commander" comes from a 4-inch sea cock located near the bow, 5 or 6 feet below the water line. It is delivered to the tank through a 4-inch pipe by means of a centrifugal pump powered by the vessel's main engine. On the "Commander" the 4-inch line is reduced to $2^1/_2$ inches prior to entering the tank. At the point of reduction a $1^1/_2$-inch hose is provided to supply additional water to the port tank when catches are large. On both vessels, the pipe enters through the side of the starboard tank near the bottom. An elbow directs the flow against the bottom of the tank. Tanks (Fig. 5) are made of $^3/_4$-inch marine plywood with outside measurements of the pair about 11 feet by 5 feet by $2^1/_2$ feet deep. Capacity is about 1000 gallons. Port and starboard compartments are separated by a plywood partition for the purpose of reducing surge of the water. Numerous $1^1/_2$-inch holes drilled in the partition insure free exchange of water between tanks, so that they have essentially a common water supply. Each compartment has a 4-foot square opening at the top bordered by an 8-inch coaming. At full flow the "Commander" tank can be filled in 5 minutes, or at the rate of 200 gallons per minute. The "Renown" rate is somewhat greater. Overflow is through holes drilled in the side and back panels of the coaming. Drains in the bottom are provided for emptying. The white fire hose illustrated in Fig. 5 is a standby supply from a separate pump available in case of failure of the main supply. It was not used in the experiments herein discussed.

Salmon were dipped 2 or 3 at a time from the bunt of the seine to the holding tanks, using long-handled dipnets hung with fine-meshed knotless webbing (Figs. 2 and 4). Fish were then individually transferred in short-handled shallow dipnets to the tagging trough mounted on the rail of the vessel (Fig. 5). Tagging troughs were lined with foam rubber and covered with smooth sheet plastic to minimize injury during tagging. If less than about 100 fish were caught, all were placed in the port tank, and tagging was done on the port side of the vessel. With large catches, fish were dipped randomly into both

tanks in approximately equal numbers. Two tagging crews then proceeded to tag simultaneously on opposite sides of the vessel (Fig. 5). The same type of tag was used on each side of the vessel, and studied efforts were made to standardize techniques of application.

The behavior of fish in both tanks was similar. They characteristically milled quietly in random circles at all depths, occasionally nosing to the surface. Visibility into the starboard tank was poorer because the turbulence of the inflow distorted the surface.

It was at first suspected that the difference in results between tanks was due to personnel, since each tagging crew always operated on the same side of the vessel whenever 2 crews were needed. Unfortunately teams did not reverse sides during simultaneous tagging for a directly comparable test, but they reversed once when anesthesia was being tested, with results as shown in Table 4. It is strongly indicated by Table 4 that the tank and not the personnel is the factor causing the disparity in success of return. The improved return from the second hour's tagging is very unusual, and reasons for this are unknown.

It is apparent then from Tables 2, 3, and 4 that there is a mortality factor in the tanks, that it is more pronounced in the starboard (inflow) side, and that it probably increases with time.

Turbulence is a logical factor to suspect, since there is much more turbulence in the inflow tank where mortality appears higher. Although the inflow is directed against the bottom of the tank, it still causes a rolling "boil" from bottom to surface. The flow into the port tank, through holes in the partition described earlier, causes noticeably less turbulence. The $1^1/_2$-inch hose, often used in the port tank to augment the water supply, caused much less turbulence than the $2^1/_2$-inch pipe feeding the opposite tank.

The question of air bubbles is mentioned because excess air bubbles are a known cause of mortality among bait fish held in tanks (Kimura, 1935; Suehiro, 1936). Whether air bubbles are a factor in the salmon tanks is unknown. At idling engine speed, very little, if any, air is visible in the water supply. Foam forms at the water's surface in varying degree, probably as a result of the turbulence. When seas are choppy, the vessel is usually put underway at slow speed which increases the water flow (since pumps are run by the main engine), thus increasing turbulence and perhaps volume of air bubbles also. Since this problem was not earlier recognized in our work, no records were kept of such conditions. It was noted occasionally that fish accumulated a layer of fine air bubbles on their skin, usually in small patches at various points on their body. Suehiro (1936) found a similar condition on sardines which had died due to abnormal amounts of air bubbles entering a bait tank. He further found such bubbles on gill lamellae of those which died, and surmised that such disruption of respiration was an important cause of mortality. He clearly showed by tests that the bubbles on the fish were not due to supersaturation of dissolved gas in his water supply.

The amounts of free oxygen in the tanks have not been measured, but data available suggest that oxygen deficiency is not a problem. It would seem that if it were, survival on the port side would be worse rather than better, since fish here must utilize water that has already passed through the fish mass in the starboard tank. Further, the tank on the vessel "Renown" has a much greater volume of water available (4" inflow), and in samples where results between vessels may be compared, survival was no better than in "Commander" samples.

Another important possible factor is supersaturation of dissolved air in the water supply, which according to Marsh and Gorham (1904) can be a serious cause of mortality among fish held in aquaria with a pump-fed water supply. Marsh and Gorham noted a serious mortality among fish held in tanks at Woods Hole, Massachusetts. The difficulty was traced to air entering through defects in the saltwater intake pipe. Compression of the water during pumping from sea level to elevated tanks caused supersaturation in the water. Fish, being unable to compensate internally for the increased gas tension in the water, became

**Table 4**

**Percent returns from red salmon released from port and starboard tanks by tagging teams No. 1 and No. 2 (Set C 46, 11 June 1960)**

| | Port tank* | | | Starboard tank | | |
|---|---|---|---|---|---|---|
| | No. released | No. returned | Percent returned | No. released | No. returned | Percent returned |
| First hour | 56 | (Team No. 1) 21 | 37.5 | 69 | (Team No. 2) 12 | 17.4 |
| Second hour | 32 | (Team No. 2) 13 | 40.6 | 42 | (Team No. 1) 10 | 23.8 |

* Anesthesia was used on fish from Port tank only, but since in all comparable tests anesthesia has shown no advantage, this factor should not bias results shown here.

ded with excess gas entering the blood through gill membranes. The excess collects in various ts of the body, causing lesions and "pop-eyes" l finally asphyxiation from gas embolism in the filaments, or heart, or both. Marsh and Gorham orted a cessation of such symptoms and mortalities en the defective inflow pipe was replaced.

t is not certain that bubble disease was a factor in tanks at sea, but conditions closely paralleled se described by the above authors. In both cases, were held in very cold saltwater supplied by trifugal pumps. Films of minute bubbles were netimes seen on fish in our tanks similar to those n at Woods Hole. Mortalities at both places parently increased with time of exposure. Our fish e not held long enough for lesions to be noted.

t is difficult to surmise how air could enter the ter supply on the vessels, unless there were flaws the pipe fittings or pumps. Water is raised approximately 8 or 10 feet from the intake to the tank ough a closed system. As explained earlier, the ake is too deep for air to enter there. Leaks on the ake side of the pump do not give out water, but k in air, and are therefore not always obvious. ere is now no way of checking whether air leaks sted, since the problem was not recognized until ently, and pumps are overhauled from time to time. sts made in the spring of 1961 aboard the vessel enown" showed no difference in $O_2$ content between nples from the tank and samples from the source ter (Puget Sound, 8.8 mg/l). This indicates that pumps do not introduce excess gas when working perly, but defects may have existed in the past.

In future high seas operations, a separate inflow npartment will be added to tanks so that fish in h port and starboard compartments will be tected from the turbulence of the inflow. Personnel l be rotated between tanks during simultaneous ging, to positively check this possible source of iation. Oxygen content of water will also be ted with varying numbers of fish in the tanks and h varying amounts of inflow, to determine optimum culation needs and to check for supersaturation. addition, floating pound-nets will be tried for ding fish during tagging on calm days, to compare h results from those held in the tank.

Long-term tests of holding salmon in the tanks with l flow of water are also needed. In 1958, 4 pink mon were kept in the starboard tank of the "Commander" for 4 days with only an occasional refreshing he water, and all appeared vigorous when removed. this case, however, flow of water was not at all nparable with conditions during tagging.

Marsh and Gorham founds some species much more istant to gas disease than others. Generalizations m behavior of other species are therefore probably not directly comparable with salmon. For example, approximately 25 Atka mackerel (*Pleurogrammus monopterygius*) caught together with the salmon were kept in the starboard tank for 60 days with no observable ill effects. They fed avidly, and were subjected to the full flow of water for several hours whenever a catch of salmon was being released. At other times, the pumps were run once or twice daily to refresh the water. During the period of full flow, they were seen feeding on the parasitic copepods on the backs of salmon.

It is possible also, that injury sustained in the net renders fish more susceptible to the mortality factors in the tank. This might partially explain the much lower return rate of chum salmon as compared to red salmon. Chums characteristically remain deep in the seine and are therefore chafed and scaled more severely by the web. Because they remain deeper they are among the last to be brailed aboard and among the last to be tagged. Thus injury and tank mortality must be more severe with this species.

### Relation of Size and Susceptibility to Injury

Salmon released in coastal areas are usually mature fish of a relatively uniform size and physiological condition, so that injury during catching and tagging, and subsequent probability of survival, are reasonably similar for all fish released. At sea, however, a far more extensive range of sizes and ages is caught, and it has become evident that the smaller and younger immature salmon are much more susceptible to injury than the larger fish. (For range of sizes see Fig. 7.) This has been manifested by greater scaling of small fish in the net and by additional scaling during tagging. In seine catches which included large masses of jellyfish the smaller salmon frequently showed welts on their sides, presumably from repeated contact with jellyfish in the bunt prior to brailing. Larger fish are apparently protected by thicker skin.

The rate of return of all chum salmon released in 1958 is shown by age in Table 5 and is further illustrated by length in Figure 7. Chum salmon were chosen for this comparison because of the range of ages available: from 1 to 6. In comparing the total return for each age group (Table 5) there is a sharp decline in percent return from the oldest to the youngest fish. It is possible that a few additional fish from among the youngest ages will be returned in 1961, but certainly not enough to alter the trend shown. If the smaller fish could be released with no more injury than the larger fish, it might be possible to compare mortality rates for fish returning in the year of tagging with those returning 1 or 2 years later. Using present methods, however, differential tagging mortality according to size must completely mask the true natural mortality from year to year.

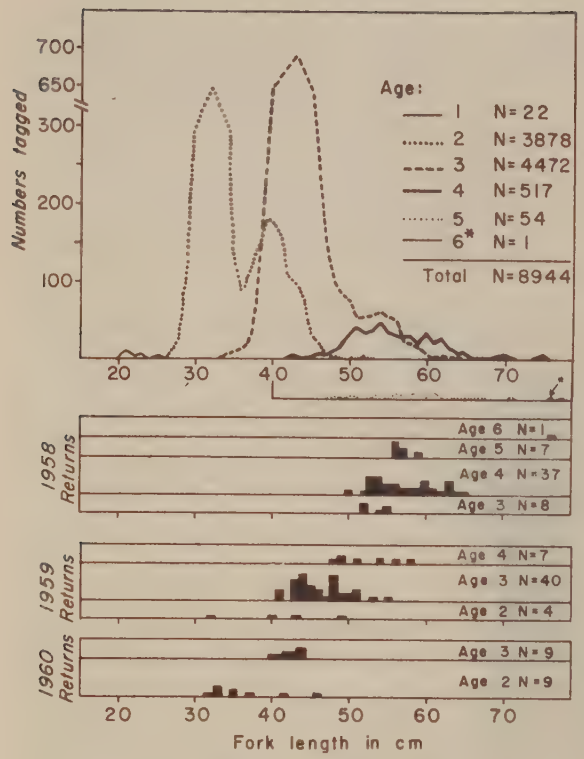


Figure 7. Lengths of tagged chum salmon released in 1958, by ocean age, and lengths at tagging of returns in 1958, 1959, and 1960.

There are also problems in comparing rates of return between two age groups of similar size such as the 4 and 5 year old chums (Fig. 7 and Table 5). The 13% return of 5 year old fish in 1958 may or may not be comparable with the 8.5% return (1958 plus 1957) of 4 year old fish. The 5 year olds may be considered mature, since very few remain an additional year. However, in the case of 4 year old fish, there might be considerable variation (according to source of the fish) in the proportion which are due to spawn at 4 years or 5 years. Thus, even within this group the annual natural mortality may not be inferred by comparing annual return rates with those of 5 year olds.

**Table 5**

**Numbers of chum salmon released in 1958, by ocean age, and returns in 1958, 1959, and 1960**

| Age | 1 | 2 | 3 | 4 | 5 | 6 | All ages |
|---|---|---|---|---|---|---|---|
| No. released* | 22 | 3878 | 4472 | 517 | 54 | 1 | 8944 |
| 1958 returns | 0 | 0 | 8 | 37 | 7 | 1 | 53 |
| Percent | 0 | 0 | 0.2 | 7.2 | 13.0 | 100.0 | 0.6 |
| 1959 returns | 0 | 4 | 40 | 7 | 0 | 0 | 51 |
| Percent | 0 | 0.1 | 0.9 | 1.4 | 0 | 0 | 0.6 |
| 1960 returns | 0 | 9 | 9 | 0 | 0 | 0 | 18 |
| Percent | 0 | 0.2 | 0.2 | 0 | 0 | 0 | 0.2 |
| Total return | 0 | 13 | 57 | 44 | 7 | 1 | 122 |
| Percent | 0 | 0.3 | 1.3 | 8.5 | 13.0 | 100.0 | 1.4 |

* Omitting 19 fish without scale samples.

There are other problems in making such comparisons of return rates. It is possible that the 4 year olds returning in 1958 and those returning in 1959 were destined for altogether different spawning areas where tag return efficiencies are not comparable. Also, an appreciable proportion returned from the Japanese high seas fishery may not even be maturing in the year of return, as are coastal returns. The same problems exist also with 2 and 3 year old fish. Finally, the larger fish within one age group undoubtedly have a better chance of survival than smaller fish of the same age. The 2 and 3 year old fish in Fig. 7, for example, show a secondary mode of much larger fish. These were mostly fish taken in the Gulf of Alaska, while the smaller fish of the same age were caught near the Aleutians. Such great differences in size would have to be considered in evaluating success of return by age.

The actual mechanism by which net and handling injuries cause mortality has not been determined. In studies of mortalities among bait fish held in tanks, Brock and Takata (1955) test the hypothesis that slime and scale loss cause loss of body fluids through osmosis to the hypertonic sea water medium. A 50 percent reduction in the salinity of water in their holding tanks was accompanied by a substantially reduced mortality, a result which agrees with their hypothesis. Brock and Takata further show a higher mortality among the smaller fish, similar to our experience with salmon. The above authors also found great variability in survival rates at both low and high salinities, and conclude there are other important causes of mortality not measured or controlled in their experiments. The same must be true in our salmon-holding procedures.

C. M. Child (1915) did considerable experimentation which indicates that a higher mortality in younger organisms should be expected. His general thesis is that the ability to become acclimatized to adverse conditions is inversely related to the rate of metabolism, and that the rate of metabolism in the older, larger animals is normally lower per unit of mass than in the younger and smaller of the same species, under the same external conditions. Further, Child (1923) states that susceptibility to any adverse conditions depends on rate of oxidative metabolism, and that effects on different organs may differ according to concentrations and time of exposure.

Such physiological reactions probably underlie the higher mortality of the smaller fish, and may account for their greater susceptibility to the adverse conditions

he tanks, as previously discussed. We have only un to investigate problems of this nature, and her studies of literature on the subject as well as l tests are contemplated.

### Anesthesia

he anesthetics MS 222 and Quinaldine were d experimentally in 1958, and were used in nerous samples in 1959 and 1960. This treatment dered fish easier to handle during tagging, and ctically eliminated scaling during tagging. Since ing at this step in handling was a problem only h smaller fish it was anticipated that the use of sthesia would materially increase returns of small at least.

A comparison of rate of return of anesthetized and n-anesthetized samples of *mature* salmon shows advantage in using anesthesia (Tables 3 vs. 4). ilarly, past samples of *immatures* show no reased rate of return among anesthetized samples, but since the variables between tanks were not earlier recognized, further tests using immature salmon are required.

### Tag Retention and Visibility

It is very desirable that tags used on salmon at sea be capable of remaining attached on rapidly growing fish for at least two years. Disc tags and tube or "spaghetti" tags have been used in experiments to date. Disc tags have yielded almost double the rate of return of spaghetti tags in the year of tagging and also one and two years later (Hartt, 1962). Reasons for this are thought to be better visibility of discs and their greater probability of recapture in gill nets. The great majority of returns from the high seas experiments have been from the Japanese high seas fleet and from Bristol Bay estuaries. Both fisheries employ gill nets. In the U.S.S.R. and in Japan coastal areas, traps and seines are the principal gear used.

Figure 8. Disc tag in position on red salmon released in 1958 and recaptured in 1960. (Two views).

We have no direct data on the shedding of either disc or tube tags from salmon at sea. Observations of tags on many returned salmon show no serious tendency toward shedding or deterioration of materials. If such a problem exists, it would, of course, bias return rates of younger fish remaining longer at sea.

Tests of many types of tags on rainbow trout held in freshwater ponds from 1955 through 1958 also showed no serious shortcomings in either discs or tubes. Such tests, however, may not be applicable to salmon at sea, because of the difference in physiological condition of the fish. The rainbows used were extremely hardy, were very resistant to handling injury, had a heavy mucus covering, and relatively thick skin. Tags might logically be expected to remain firmly attached to fish in this condition.

Figure 8 illustrates a disc in position at recapture on a red salmon released in the summer of 1958 and returned in the summer of 1960. The fish grew from 33.0 cm at tagging to 61.0 cm at return. It appears from the side view that the tag had migrated upward about one-half its diameter leaving a path of smooth dark scar tissue in its wake. The un-numbered disc is obviously imbedded and overgrown in scar tissue at the upper edge, and the remainder of the tag is forcing a depression in surrounding tissue. The numbered disc is forcing a depression in smooth scar tissue on all sides with a slight rim of overgrowth forming at the top. It would seem that in this example, retention is excellent. Obscuring by overgrowth might become a problem on fish growing much more than this.

In order to test the return rate of a larger and more obvious tag, $^3/_4$ inch red and white discs were tried on some mature salmon in 1959, while others were tagged with the standard $^1/_2$ inch white discs and $^1/_{16}$ inch white tubes as in previous years. The larger discs yielded much better results, as shown below for mature pink salmon:

| Type of tag | No. released | No. returned | Percent returned |
|---|---|---|---|
| $^3/_4$″ red & white disc ..... | 1970 | 157 | 8.0 |
| $^1/_2$″ white disc ..... | 447 | 7 | 1.3 |
| $^1/_{16}$″ white tube (13″ long) .. | 452 | 4 | 0.9 |

Return rates of the $^1/_2$ inch discs and of the tube tags were similar to rates in 1957 and 1958, showing that the larger discs greatly enhanced tag returns. Red and chum salmon tag returns also indicated a better return rate for the larger tags, though in 1959 too few mature fish of these species were released with the three types of tags for a critical comparison. Improved visibility is probably the key factor in the higher return rate for the larger tags.

In 1960 nearly all salmon were tagged with the larger red and white discs. The rate of return of mature red salmon from experiments in the eastern

Figure 9. Tube tag wounds on chum salmon two years a tagging. (Showing both sides)

Bering Sea, where results may be directly compar increased from 23.3% ($^1/_2$″ discs) in 1958 to 41.8 ($^3/_4$″ discs) in 1960. The increase was partly due increasing the reward from $ 1.00 to $ 25.00 a to increased fishing effort in 1960, but since t fishery in 1960 took less than half the estimated to run, the 41.8% return must indicate that the t are very efficient as to retention and visibility. Da are not yet available for evaluating the $^3/_4$ inch t on immature salmon.

We have also had opportunity to observe tu tags after two years at liberty. Tags were still firm attached, although the puncture wound was elonga posteriorly due to chafing by the trailing portion the tag. Figure 9 shows a tube tag after 2 years o salmon at sea. Because of the much lower rate return, tube tags will be discontinued in futu experiments.

Data on tag returns in 1960 indicate that tangling of disc tags in gill nets is an important fac in the retention in the nets of salmon which otherw might escape. Further, it is not infrequent that t are left tangled in gill nets while the fish pulls free a escapes. From a total of 512 tags recovered in Bris Bay in 1960, there were 9 instances when fisherm included the unsolicited remark that the tag al was found in the net while the fish had escap Personnel doing tag recovery personally observed such case. The fact that Bristol Bay reds were smal 1960 probably increased the incidence of fish escapi

The retention in gill nets of salmon by the ta together with retention of tags even when fish escap was sufficient in 1960 that the usual size selecti by gill nets was not evident among disc-tagged saln recaptured in this type of gear. In the upper hal Fig. 10 the usual selectivity of the Bristol Bay gill- catch is illustrated by the catch versus escapem

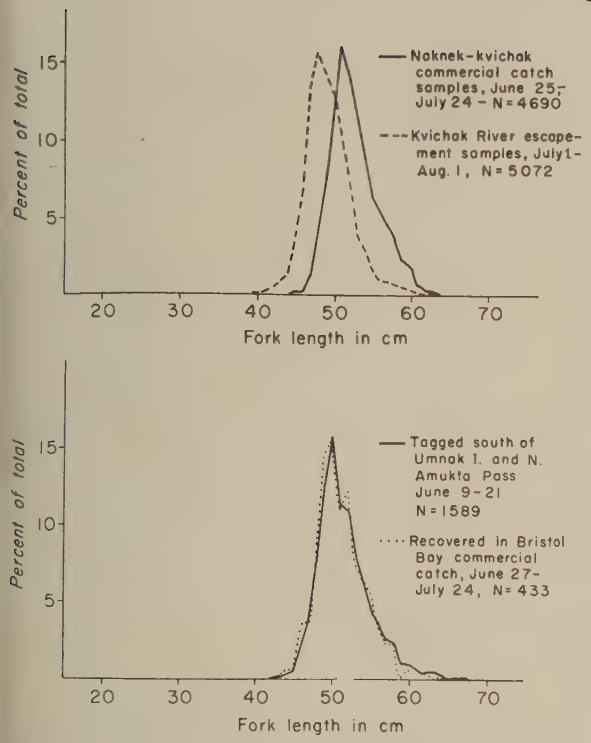


Figure 10. Upper: Lengths of red salmon, 1956-catch vs. escapement. Lower: Lengths of red salmon, 1960-tagged vs. recovered.

length-frequency curves for 1956. It should be explained that there is some bias in this figure because escapement lengths only show Kvichak River fish, whereas catches show a mixture of Naknek and Kvichak River fish, but the overwhelming proportion of Kvichak fish in 1956 renders such bias unimportant. Further, the selectivity shown is typical for other rivers in Bristol Bay where exactly the same stocks have been measured in both catch and escapement.

The lower part of Fig. 10 is in sharp contrast and indicates practically no selectivity by the Bristol Bay fishery of fish released at sea in 1960. Thus, the presence of disc tags renders all sizes of fish equally vulnerable to gill nets. This suggests that visibility accounts for only a part of the higher return rate of discs as compared to tubes. An important advantage is in the effectiveness of gill nets to hold disc-tagged salmon. This is further attested by our 1955 results when we tagged in the Gulf of Alaska, where seines, traps, and trolling gear accounted for a large part of tag returns. In that case, discs yielded 13.7% (83 of 604) returns; only slightly better than tubes; 12.6% (98 of 775) (INPFC Annual Report for 1955).

## Summary and Conclusion

Considerable progress has been made in recent years in developing methods for successfully tagging salmon on the high seas. Gear and methods have been constantly observed, tested, and modified as the need was seen to improve survival of released fish.

It is apparent that the success of return of salmon tagged on the high seas is dependent upon a series of interdependent variables, many of them yet unmeasured. Survival depends upon condition of the fish as taken from the fishing gear, their species, size and age, numbers in haul, time spent in holding tanks (plus the physical conditions in the tank) and mechanics of handling. The type of tag used, the gear used in recapture, and the length of time that fish may be at liberty before recapture also affect success of return, as in coastal experiments.

A principal problem now requiring solution is that of mortality caused by holding tanks. This will require investigation of the chemical and physical properties in the water supply and perhaps of the physiology of the fish while in the tanks. A satisfactory solution to this problem should result in improved return rates, particularly of the younger age groups, and is a necessary first step in evaluating survival of the several age groups.

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# C. REPORT ON THE INVESTIGATIONS BY THE UNITED STATES FOR THE INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION—1961

Bureau of Commercial Fisheries, April, 1962

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## INTRODUCTION

As a part of the Commission's research into problems defined in the Protocol to the Convention, the United States has undertaken to study certain aspects of the salmon in the high seas. The studies have been planned jointly with those pursued by Canada and Japan, and the cooperative effort was designed to provide an integrated approach to the solution of the more critical questions. The United States has studied the origin, movements, distribution and abundance of salmon in the North Pacific Ocean and Bering Sea as well as some of the environmental factors influencing their distribution and abundance. Studies of the king crab of the eastern Bering Sea and its fishery have been conducted on a cooperative basis with Japan.

The purpose of the following reports is to provide information regarding the studies in progress and their status at the end of 1961. For convenience the reports are presented according to the units in which the work was done. The investigation of distribution, abundance, and migration of salmon are reported under Tagging Studies and Salmon Distribution and Abundance on the High Seas. Study of the factors controlling these are reported under Oceanography. Progress in determining the origin of salmon on the high seas is reported under Salmon Serology, Morphological Classification of 1960 Red Salmon, Red Salmon Scale Studies, Pink Salmon Studies, and Chum Salmon Studies.

The tagging work was performed by the Fisheries Research Institute of the University of Washington. The remainder was done by the Seattle Biological Laboratory of the United States Bureau of Commercial Fisheries.

## TAGGING STUDIES

by A. C. Hartt

High seas salmon tagging research by the United States in 1961 consisted of two major projects, a two-vessel operation in the Aleutian area similar to that of previous years, plus a new two-vessel operation in the Gulf of Alaska. Work in both areas was done by the Fisheries Research Institute of the University of Washington under contract with the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries. For convenience, operations in the two areas will be reported separately.

### Aleutian Area Tagging

The purse seine vessels *Commander*, 81 feet, and *Renown*, 85 feet, were chartered for the 1961 Aleutian salmon tagging operations. Both vessels departed Seattle April 27. The *Commander* returned September 3, and the *Renown*, September 9.

Purse seines were similar to those described for 1960. The water inflow in fish holding tanks was altered to reduce turbulence.

International North Pacific Fisheries Commission, Annual Report 1961, Vancouver, Canada, 1963, p. 83-91.

Three types of tags were used. Red and white disc tags $\frac{3}{4}$-inch in diameter were used on most mature fish and on the larger immatures. White discs $\frac{1}{2}$-inch in diameter and white tubes $\frac{1}{16}$-inch in diameter were used on the smaller immatures.

The anesthetic MS 222 was used on some samples in order that tagged fish could be weighed.

Principal objectives in 1961 were fourfold:

1. To tag all species of salmon along the Aleutians to compare distribution of Asian and American salmon with that of previous years.

2. To make particular effort to tag mature red salmon in western Aleutian areas (Kiska-Attu) early in the season.

3. To find routes, timing, and relative abundance of major flows of mature red salmon approaching Bristol Bay during June.

4. To obtain an index of abundance of immature red salmon in the central and western Aleutians in July and August.

Table 1 presents the totals tagged by area and by species. Figure 1 illustrates the areas referred to in the table.

Objective 1 was carried out satisfactorily as far

TABLE 1. Numbers of salmon tagged in Aleutian areas—1961.

| Area[1] | Inclusive dates | No. of seine sets | Numbers tagged by species | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Red | Chum | Pink | Silver | King | Steelhead | TOTAL |
| E7550 | 8/ 7–8/16 | 7 | 431 | 94 | 2 | 12 | 8 | — | 547 |
| 8052 | 6/23–7/9 | 4 | 5 | 66 | 8 | — | — | — | 79 |
| 8050 | 6/ 6–8/23 | 52 | 1390 | 2043 | 1275 | 11 | 20 | — | 4739 |
| W7550 | 7/ 7–7/20 | 4 | 5 | 116 | 8 | 1 | 1 | — | 131 |
| W7054 | 6/23 | 4 | 77 | 24 | 5 | — | 5 | — | 111 |
| W7052 | 5/14–7/27 | 37 | 3144 | 1617 | 892 | 5 | 34 | — | 5692 |
| W6556 | 6/24–6/26 | 4 | 362 | 17 | — | — | 3 | — | 382 |
| W6554 | 5/11 | 2 | — | 1 | — | 1 | — | — | 2 |
| TOTAL | | 114 | 5414 | 3978 | 2190 | 30 | 71 | — | 11683 |

[1] See Figure 1.

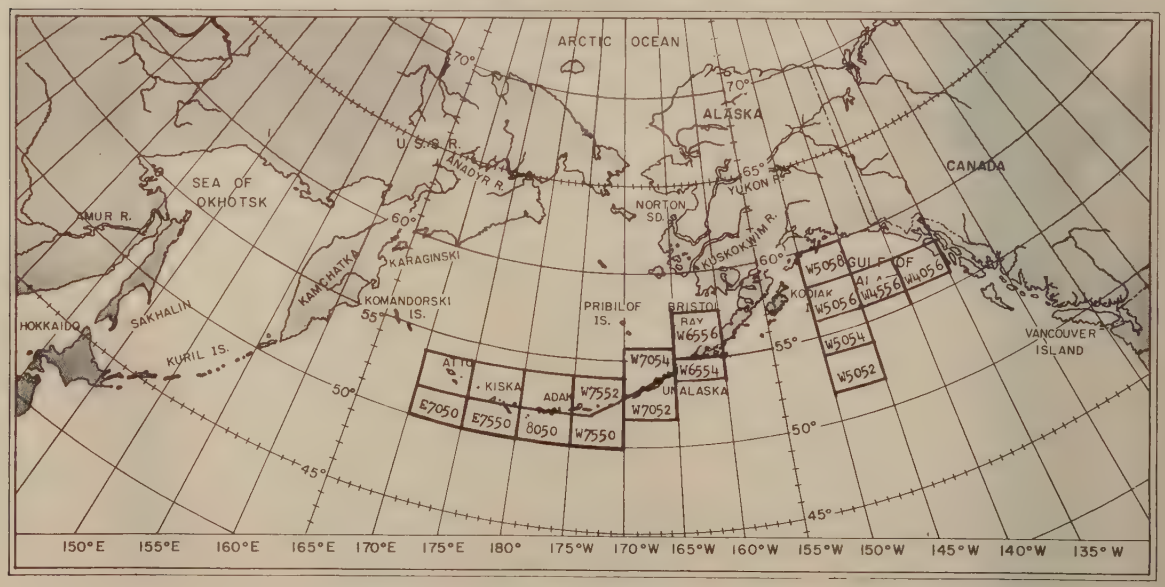


FIGURE 1. Reference map with key to area code.

west as 175°E. longitude. Large numbers of mature reds, chums, and pinks were tagged from early June in central and eastern Aleutians. Immature reds and chums were tagged between Umnak and Kiska from late June to mid-August. Pinks were plentiful during June and were moving strongly westward.

We failed to achieve objective 2 because of bad weather during mid- and late May.

Objective 3 was fulfilled satisfactorily. Seine catches showed large numbers of mature reds passing westward on the south side of both eastern and central Aleutians indicating a major flow of reds approaching Bristol Bay via Amukta Pass (172°W.) and Amchitka Pass (180°) (see Fig. 2). Presumably, reds also approached from further west as observed in previous years, but as mentioned earlier, weather prevented seining in western areas early this year. Results of Japanese tagging early in the season and far to the west, however, confirm that important numbers of reds approached Bristol Bay from as far west as 165° E. longitude. The average seine catch of mature red salmon south of Adak was 82 compared with 75 in 1960, while south of Umnak it was 214 this year compared with 125 in 1960 for comparable dates.

Objective 4 was fulfilled satisfactorily. It was noteworthy that the center of abundance of immature reds passing westward south of Adak in 1961 was apparently about 25 to 35 miles offshore. Catches at this distance offshore averaged 58 reds as against eight reds in the usual inshore index area. South of Adak reds were over 85 percent 1-winter immatures, while further west, south of Kiska, they were only about 50 percent 1-winter age. It is hoped that sufficient returns will be received in 1962 to show whether these two groups have different origins.

Tag recovery efforts in 1961 were similar to those of 1960 except that the $25 reward for fish with tags attached was discontinued. The usual $1 reward was offered, with emphasis on the return of fish with tag attached. A special award of $300 was also made by the Alaska Fishermen's Union for one tag drawn from all tags received through September 15. This undoubtedly bolstered tag returns. Tag recovery effort for the several coastal tagging experiments by the U. S. Fish and Wildlife Service and the Alaska Department of Fish and Game also helped the high seas tag return this year. Tag recovery at Igiugig on the Kvichak River using small explosive charges was undertaken again in 1961 and resulted in the capture of 35 fish bearing tags from high seas experiments.

Prior to discussing tag returns, it should be pointed out that at time of writing, returns are nearly complete from United States and Canadian coastal areas, and from the Japanese high seas fleet. However, based on previous years' experience, additional chum returns may be forthcoming from Japan, and additional chum and pink returns should be received from the U.S.S.R.

Figures 2 and 3 show 1961 red salmon returns to date. The 573 mature reds tagged south of Adak (Fig. 2) yielded 40 returns from Bristol Bay, plus 27 from the high seas. The high seas returns again illustrate the migration path toward Bristol Bay as shown in previous years. The lack of returns from the heavy high seas fishery to the west and the lack of Asian coastal returns emphasize that the large run of reds passing this area must have been almost

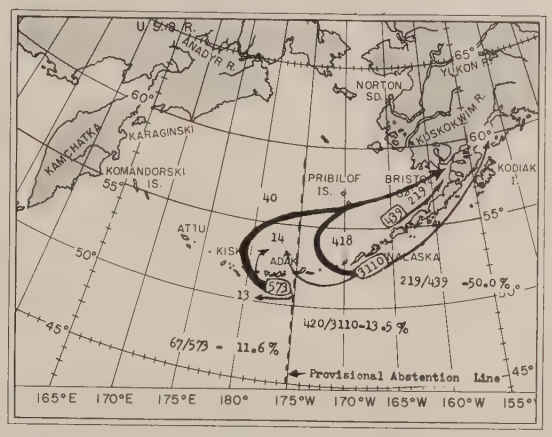


FIGURE 2. Recovery distribution of reds tagged in 1961—recovered in 1961.

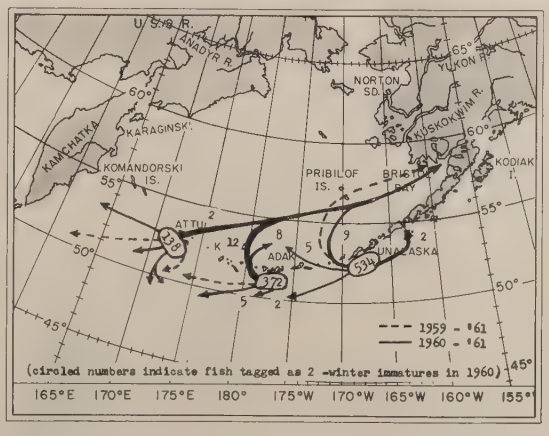


FIGURE 3. Recovery distribution of reds tagged in 1959 and 1960—recovered in 1961.

wholly Bristol Bay fish. The 13 returns from south of Adak is a departure from previous years and may indicate expansion of the Japanese fleet into this area where Bristol Bay reds have been shown to concentrate each year. The 14 from north of Adak indicate a heavy take of Bristol Bay reds here as in 1956, 1957, and 1960. The 11.6 percent overall return compares with a 13.6 percent return from releases in this area in 1960.

The 3,110 reds tagged south of Umnak yielded 418 returns from Bristol Bay, one from Cook Inlet, and one from the high seas north of Adak. This overall return rate might have been larger if not for the fact that some of the seine catches in this area were very large and fish were held a long time in the tanks, or in the bunt of the seine, which undoubtedly reduced survival. Some smaller samples yielded 30 percent returns, comparable with the results in 1960. The distribution of returns indicates that the reds passing this area were also almost wholly destined for Bristol Bay, and that few of this group traveled west of the provisional abstention line (175°W.) before entering the Bering Sea.

The 439 tagged in the Bering Sea between 161° and 166° W. longitude yielded 219 returns, all from Bristol Bay. The 50 percent overall return rate compares with approximately 35 percent in 1960, but most tagging in 1961 was much closer to the fishery than in 1960.

Opposed seine sets again showed the great predominance of the westward movement south of the Aleutians. On June 17, south of Umnak, for example, three consecutive sets yielded the following:

Set #1—open East—170 salmon
Set #2—open West—0 salmon
Set #3—open East—448 salmon.

Returns in 1961 of 54 reds tagged as immatures in 1959 and 1960 are illustrated in Figure 3. The arrows are drawn for convenience and are not intended to indicate migration routes during the year at liberty.

The usual pattern of predominance of Bristol Ba fish in all areas of tagging is evident.

The high seas returns reflect the areas of concentra tion of Bristol Bay reds north and south of Adak described for mature fish sampled in these areas. Th returns from south of Attu and Kiska were very like Bristol Bay reds judging by date and location of r capture since all were recaptured prior to June The three recaptured west of 170°E., however, we most probably Kamchatkan reds since they we recaptured between June 22 and July 6. It is perha meaningful that all three had been released in th Attu area.

It is also important that seven of the 18 return from immature reds tagged in 1960 in the easter Aleutians, south of Umnak Island, were from th high seas fishery north and south of Adak in 196 Thus, unlike mature reds tagged in this area, im matures travel well west of the provisional abstentio line during their year of liberty, and are exposed t high seas fishing.

The two recovered at Cape Lutke (south sid Unimak Island) might furnish a clue to the migratio route of reds between summer of one year and sprin of the following year. Since immature reds mov strongly westward along the south side of the Aleutian from late June through August, and since matur reds again move westward in the eastern Aleutians th following June, there is the question of whether par of the fish move eastward again during the winte The location of these two returns suggests that the had moved eastward to repeat the westward movemen as matures. Previous years' tagging has shown tha many reds were found well to the west early the fo lowing spring and probably did not return east durin the winter. As mentioned earlier, Japanese taggin in 1961 showed Bristol Bay reds in abundance as fa west as 165° E.

The return by age group from 1960 is also of cor siderable interest. As shown in Table 2, the overa rate of return after a year at liberty was 0.2 percer for 1-winter fish and 4.6 percent for 2-winter fis

Table 2. Percent return by age group and area of release of immature reds tagged in 1960 and recovered in 1961.

| Area of release | Number released in 1960 as 1-winter | Number returned in 1961 as 2-winter | Percent returned | Number released in 1960 as 2-winter | Number returned in 1961 as 3-winter | Percent returned |
|---|---|---|---|---|---|---|
| Attu | 71 | 0 | 0 | 138 | 6 | 4.3 |
| Adak | 163 | 0 | 0 | 372 | 26 | 7.0 |
| Umnak | 909 | 2 | 0.2 | 534 | 16 | 3.0 |
| Total | 1,143 | 2 | 0.2 | 1,044 | 48 | 4.6 |

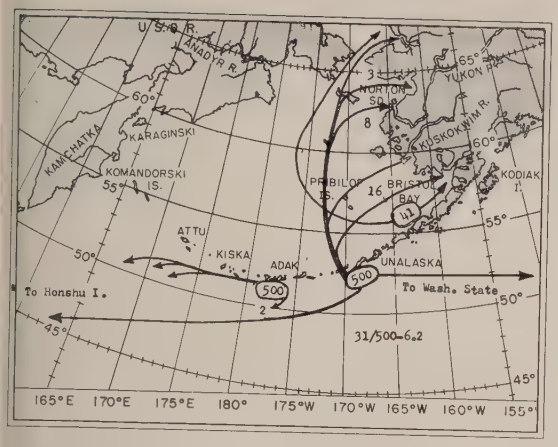


FIGURE 4. Recovery distribution of chums tagged in 1961—recovered in 1961.

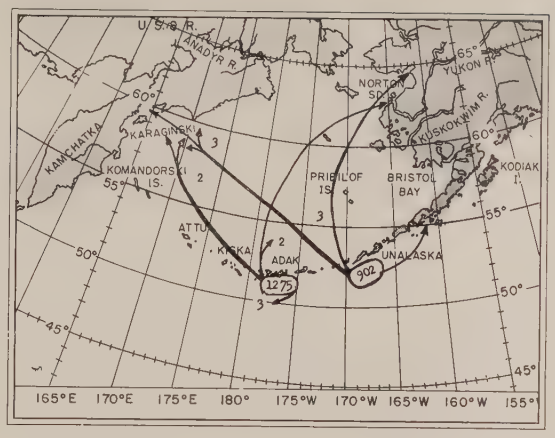


FIGURE 5. Recovery distribution of pinks tagged in 1961—recovered in 1961.

Additional returns from the 1-winter group may be received in 1962.

Figure 4 illustrates chum salmon returns to date. Numbers of matures tagged are preliminary estimates.

Of 31 returns from about 500 releases south of Umnak Island, one was from Honshu, one was from the State of Washington, and the remainder from the northwest coast of Alaska. The one from Washington was of particular interest since it was taken on rod and reel in the Hama Hama River on December 21, 1961. The 500 matures tagged south of Adak yielded only seven high seas returns. It is likely that there will be U.S.S.R. coastal returns and possibly additional Japanese coastal returns from 1961 chum releases.

In addition, the following chums were returned in 1961 from releases of immatures: one from 1957, two from 1958, three from 1959, and 10 from 1960. All were from the Japanese high seas fishery, and recovery points were far west of release points.

Figure 5 illustrates pink salmon returns to date. The outstanding feature is the return in an odd year of pinks from both continents. In 1957 and 1959, large numbers were tagged, yet returns came only from East Kamchatka or intermediate high seas points. In view of the small number of high seas returns, there should be additional returns from the U.S.S.R. The one return from the south side of the Alaska Peninsula is the first evidence of pinks moving eastward from Aleutian tagging. However, it should be pointed out that this specimen was not from among the main body of pinks which passes westward in June. It was taken on July 21 when pinks were relatively scarce. Further, opposed sets of the seine showed pinks to be moving predominantly eastward at this time and location. This suggests that some pinks destined for the Alaska Peninsula pass eastward through these waters following the westward passage of East Kamchatkan and northwest Alaskan pinks.

No cohos, and but one chinook salmon have been returned to date. The chinook was tagged north of Unimak Island and recovered at Egegik in Bristol Bay.

## Gulf of Alaska Tagging

Vessels chartered for the Gulf of Alaska tagging were the purse seiners *Ocean Pride*, 87 feet, and the *Storm*, 81 feet. The *Ocean Pride* departed Seattle May 22, and returned August 31. The *Storm* departed May 16, and returned October 5.

Seine gear, methods, and types of tags of Gulf vessels were similar to those previously described for the Aleutian operations. Because the Gulf tagging contract was not received until mid-April, there were problems in getting seine materials in time for departure of the Gulf boats in mid-May. The *Storm* was able to depart May 16 by using the seine normally carried as a spare for Aleutian operations. The upper two strips of the *Storm* seine were of very fine ($1\frac{1}{2}$-inch) herring web because $2\frac{1}{2}$-inch web was not readily available. The *Ocean Pride* seine was new, entirely of synthetic knotless material, and proved very efficient.

Objectives of the Gulf operation were:

1. To learn the ocean distribution, timing, and

movements of major stocks of salmon originating in streams tributary to the Gulf of Alaska.

2. To learn the eastern limits and relative abundance of Bristol Bay red salmon and northwest Alaskan chums and possibly pinks in the Gulf of Alaska.

The *Ocean Pride* was assigned seven stations in t eastern half of the Gulf and the *Storm* seven stati in the western half, north of 54°N. Stations includ both inshore and offshore areas. In addition, *Commander* and *Renown* made several sets in the G as they were en route to and from the Aleutian

Table 3. Numbers of salmon tagged in Gulf areas—1961.

| Area[1] | Inclusive dates | No. of sets | Number tagged by species | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Red | Chum | Pink | Silver | King | Steelhead | Total |
| W6054 | 8–30 — | 3 | 2 | 6 | 0 | 0 | 5 | 0 | 13 |
| W5558 | 6–14 9–13 | 11 | 36 | 30 | 8 | 1 | 23 | 0 | 98 |
| W5556 | 6– 2 9– 8 | 28 | 189 | 70 | 31 | 3 | 179 | 0 | 472 |
| W5554 | 6–22 — | 2 | — | — | | | — | — | — |
| W5552 | 7–28 — | 3 | 33 | 26 | 1 | 2 | 0 | 0 | 62 |
| W5060 | 9–16 9–20 | 6 | 9 | 54 | 54 | 0 | 60 | 0 | 177 |
| W5058 | 5– 4 9–15 | 38 | 40 | 472 | 133 | 3 | 207 | 0 | 855 |
| W5056 | 6– 3 8– 7 | 16 | 50 | 193 | 64 | 15 | 5 | 8 | 335 |
| W5054 | 6–23 7–26 | 10 | 53 | 96 | 42 | 5 | 3 | 1 | 200 |
| W4558 | 6– 4 9–21 | 23 | 68 | 290 | 378 | 63 | 286 | 0 | 1,085 |
| W4556 | 5–23 8– 4 | 16 | 20 | 59 | 148 | 2 | 1 | 1 | 231 |
| W4554 | 6–18 8– 3 | 15 | 8 | 85 | 119 | 0 | 4 | 2 | 218 |
| W4552 | 8– 2 — | 4 | 1 | 12 | 0 | 0 | 1 | 0 | 14 |
| W4058 | 5– 3 9–22 | 21 | 34 | 103 | 394 | 12 | 327 | 0 | 870 |
| W4056 | 5–28 9–26 | 31 | 51 | 257 | 545 | 21 | 172 | 3 | 1,049 |
| W3050 | 9 29 — | 3 | 0 | 10 | 7 | 0 | 1 | 0 | 18 |
| W3048 | 8–28 — | 2 | 0 | 0 | 2 | 0 | 6 | 0 | 8 |
| W2548 | 8 30 — | 1 | 1 | 0 | 12 | 60 | 260 | 0 | 333 |
| Grand Total | | 233 | 595 | 1,763 | 1,938 | 187 | 1,540 | 15 | 6,038 |

[1] See Figure 1.

Table 3 lists numbers of salmon tagged by the area and species. Figure 1 illustrates the code system for areas of tagging (2° Lat. × 5° Long.).

As may be seen from Table 3, the average numb of salmon tagged per set was approximately 26. general, larger catches were made at stations clos

Table 4. Recoveries of red salmon tagged in the Gulf of Alaska in 1961 (tags received through January 1, 1962).

| Recovery area | Area of release (see Fig. 1) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | W5556 | W5058 | W4558 | W4556 | W4058 | W4056 | W2548 | Total |
| Bristol Bay | 1 | | | | | | | 1 |
| South side Alaska Peninsula | 2 | | | | | | | 2 |
| Kodiak Island | 2 | | | | | | | 2 |
| Cook Inlet | 1 | | 1 | | | | | 2 |
| Cook Inlet to Prince William Sound | | | | | | | | 0 |
| Prince William Sound | | | | | | | | 0 |
| Copper River | 1 | 1 | | 1 | 2 | | | 5 |
| Copper River to Cape Spencer | | | 3 | | 1 | | | 4 |
| S.E. Alaska north of 56° | | | 1 | | 9 | 1 | | 11 |
| S.E. Alaska south of 56° | | | | | | 1 | | 1 |
| Skeena River | | | | | | 4 | | 4 |
| Queen Charlotte Sd. | | | | | | 2 | | 2 |
| West Coast Vancouver I. | | | | | | | 1 | 1 |
| Johnstone Strait | | | | | | | | 0 |
| Total | 7 | 1 | 5 | 1 | 12 | 8 | 1 | 35 |

to the coast, probably because of the "leading" effect of the coastline. The direction of movement of salmon at the time of catch was often mixed, but in some areas rather definite patterns were evident. The catch data when broken down by specific location, by direction of movement, by species, and by maturity, should contribute considerable new knowledge of salmon movements in the Gulf.

Returns from the Gulf experiments received through January 1, 1962, are summarized in Tables 4 through 3. Figures 6, 7, and 8 show the general recovery patterns for red, chum, and pink salmon respectively. Every return could not be conveniently illustrated because of the large number of release points and the mixed pattern of movement.

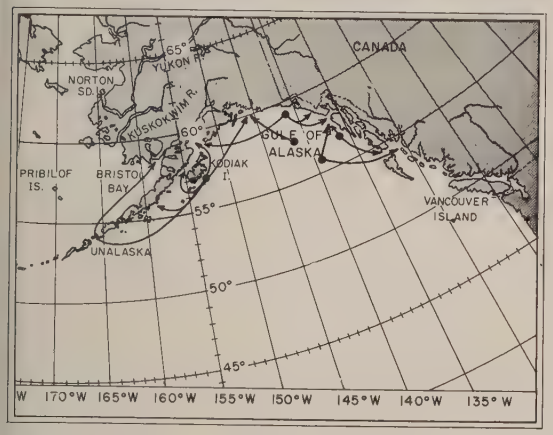


FIGURE 6. Diagram of general recovery pattern of red salmon tagged in the Gulf of Alaska in 1961. (All returns not shown because of space limitation—see Table 4.)

Purse seine catches were markedly smaller in the Gulf of Alaska than in the Aleutian Islands area. In general, tag returns indicate that fish tagged at any one station are destined for a variety of spawning grounds. Even at inshore stations, fish often moved north, south, east, and west from a single tagging point. However, data to date do suggest some general trends in some cases. Further analysis by date of release and by size of runs to recovery areas is needed.

Red salmon were found in limited numbers in most areas of fishing. The 35 returns (Table 4 and Fig. 6) are from approximately 225 mature reds tagged, or 15.6 percent. Table 4 and Figure 6 indicate considerable mixing of reds destined for various spawning areas. Because bad weather limited fishing, insufficient numbers of reds were tagged early in the season in the western areas to show the full distribution of reds passing through these waters. In 1958, for example, 26 reds tagged south of Kodiak Island yielded five returns from the approaches to the Fraser River, and in 1959, six reds tagged in the same area yielded one return from the Fraser and one from Bristol Bay. Since the western Gulf is apparently an important feeding area for immature red salmon, early tagging here on a large scale should result in more widespread returns than that shown in Table 4. Immature reds were tagged in small numbers over wide areas in 1961 and should yield valuable return data in 1962. The lack of appreciable catches of immature reds suggests that our vessels did not encounter the main bodies of immature Fraser River fish.

TABLE 5. Recoveries of chum salmon tagged in the Gulf of Alaska in 1961 (tags received through January 1, 1962).

| Recovery area | Area of release (see Fig. 1) | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| | W5558 | W5556 | W5058 | W5054 | W4558 | W4556 | W4058 | W4056 | |
| Bristol Bay | | | | | | | | | 0 |
| South side Alaska Peninsula | 1 | 3 | 1 | | | | | | 5 |
| Kodiak Island | | 2 | 1 | | | | | | 3 |
| Cook Inlet | | | | | | | | | 0 |
| Cook Inlet to Prince William Sound | | | 1 | | | | | | 1 |
| Prince William Sound | 2 | | 4 | | | | | | 6 |
| Copper River | | | | | | | | | 0 |
| Copper River to Cape Spencer | | | | | | | | | 0 |
| S.E. Alaska north of 56° | | | 3 | 1 | 28 | 1 | 13 | 2 | 48 |
| S.E. Alaska south of 56° | | | 1 | 1 | | | | 1 | 3 |
| Skeena River | | | | | | | | | 0 |
| Queen Charlotte Sd. | | | | | | | | 1 | 1 |
| West Coast Vancouver I. | | | | | | | | | 0 |
| Johnstone Strait | | | | | | | | | 0 |
| TOTAL | 3 | 5 | 11 | 2 | 28 | 1 | 13 | 4 | 67 |

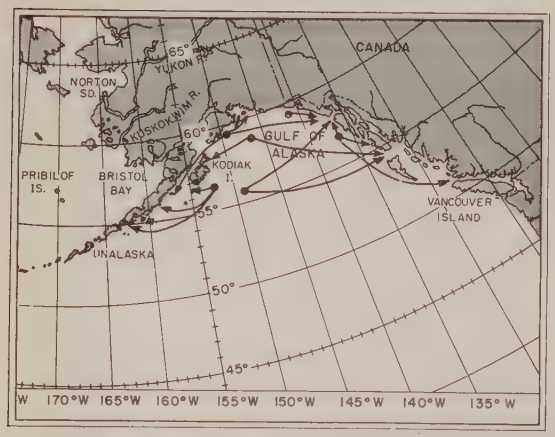


FIGURE 7. Diagram of general recovery pattern of chum salmon tagged in the Gulf of Alaska in 1961. (All returns not shown because of space limitation—see Table 5.)

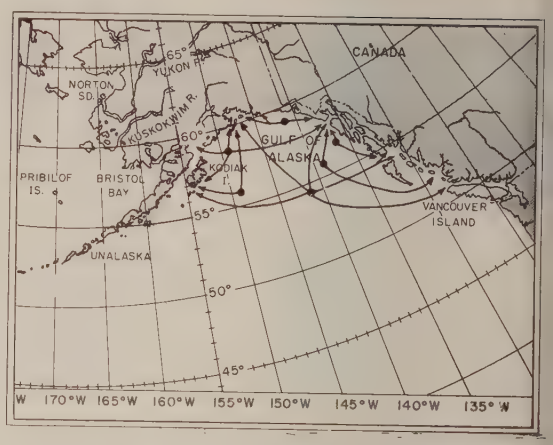


FIGURE 8. Diagram of general recovery pattern of pink salmon tagged in the Gulf of Alaska in 1961. (All returns not shown because of space limitation—see Table 6.)

TABLE 6. Recoveries of pink salmon tagged in the Gulf o Alaska in 1961 (tags received through January 1, 1962).

| | Area of release (see Fig. 1) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recovery area | W5558 | W5556 | W5058 | W5056 | W5054 | W4558 | W4556 | W4554 | W4058 | W4056 | TOTAL |
| Bristol Bay | | | | | | | | | | | 0 |
| South side Alaska Peninsula | | | | | | | | | | | 0 |
| Kodiak Island | 7 | | 2 | 7 | | | 1 | | | | 17 |
| Cook Inlet | | 1 | | | | | | | | | 1 |
| Cook Inlet to Prince William Sound | | | | | | | | | | | 0 |
| Prince William Sound | | 14 | 3 | 2 | 6 | 3 | 3 | 2 | | | 33 |
| Copper River | | | | | | | | | | | 0 |
| Copper River to Cape Spencer | | 1 | | | 6 | | | | | | 7 |
| S.E. Alaska north of 56° | | 5 | | 1 | 52 | 6 | 1 | 45 | 29 | | 139 |
| S.E. Alaska south of 56° | | | | | | 1 | 2 | | 7 | | 10 |
| Skeena River | | | | | | 1 | 2 | | 8 | | 11 |
| Queen Charlotte Sd. | | | | | | 1 | 1 | 1 | 9 | | 12 |
| West Coast Vancouver I. | | | | | | | | | | | 0 |
| Johnstone Strait | | | | | | 1 | 1 | | | | 2 |
| TOTAL | 7 | 21 | 5 | 10 | 64 | 13 | 11 | 48 | 53 | | 232 |

Chum salmon returns are listed in Table 5 and illustrated diagrammatically in Figure 7. The percent return based on a preliminary estimate of number of matures is 9.3 percent (67 out of 720 matures tagged). In general, an eastward movement seems to prevail, suggesting that main feeding areas are in the western part of the Gulf. This is in keeping with the fact that the vessel operating in the western part of the Gulf caught many more immature chums than did the vessel in the eastern half. Returns in 1962, of salmon tagged as immatures, should add considerably to the migration pattern.

Pink salmon yielded an overall return of 232 out of 1,542 matures tagged, or 15.0 percent. As shown in Table 6 and Figure 8, returns from most release points were from widespread locations. This suggests that pinks from all Gulf stocks are mixed widely at sea. Almost 400 immature pinks were tagged late in the season at several inshore stations, but the probability of recoveries in 1962 is slight because of the very small size of pinks at that stage of their life.

Tables 7 and 8 list returns of coho and king salmon respectively. Seventeen cohos were returned from 187 matures tagged, or 9.1 percent. Fourteen kings were returned from 1,540 released. These have not been classified by maturity. A large proportion of

TABLE 7. Recoveries of coho salmon tagged in the Gulf of Alaska in 1961 (tags received through January 1, 1962).

| Recovery area | Area of release (see Fig. 1) | | | | | | |
|---|---|---|---|---|---|---|---|
| | W5058 | W5056 | W5054 | W4558 | W4056 | W2548 | TOTAL |
| Copper River | 1 | 1 | | 1 | | | 3 |
| Copper River to Cape Spencer | | | 1 | 2 | | | 3 |
| S.E. Alaska north of 56° | | | | | 1 | | 1 |
| S.E. Alaska south of 56° | | | | 3 | | | 3 |
| Washington Coast | | | | | | 1 | 1 |
| Fraser River | | | | | | 3 | 3 |
| Puget Sound | | | | | | 3 | 3 |
| TOTAL | 1 | 1 | 1 | 6 | 1 | 7 | 17 |

TABLE 8. Recoveries of king salmon tagged in the Gulf of Alaska in 1961 (tags received through January 1, 1962).

| Recovery area | Area of release (see Fig. 1) | | | |
|---|---|---|---|---|
| | W4558 | W4058 | W2548 | TOTAL |
| Copper River to Cape Spencer | | 1 | | 1 |
| S.E. Alaska north of 56° | 2 | 3 | | 5 |
| West Coast of Vancouver I. | | | 2 | 2 |
| Strait of Juan de Fuca | | | 5 | 5 |
| Fraser River | | | 1 | 1 |
| TOTAL | 2 | 4 | 8 | 14 |

ings tagged were small immature fish, but large nough that returns in 1962 and 1963 should be ubstantial.

A single steelhead was returned from the 15 tagged. t was released near Baranof Island off Southeast Alaska and recovered in Queen Charlotte Sound. Maturity of the steelhead tagged has not been determined.

*Note*: Since submission of the above report on U. S. high seas tagging for 1961, an additional 26 tags were received from the U.S.S.R. Table A summarizes these returns by species, year, and area. The one red salmon returned is of particular interest. It was tagged as a 2-winter age immature fish south of Adak on July 9, 1960, and recovered July 25, 1961, in the Kamchatka River estuary. This is the easternmost tagging to date that has yielded a red salmon return from the Asian coast.

TABLE A. Release and recovery data for 26 U.S. tags returned by the U.S.S.R. in March, 1962.

| No. of recovered fish | Species | Year tagged | Year recovered | Area of tagging | Recovery location |
|---|---|---|---|---|---|
| 1 | Red | 1960 | 1961 | 8050 | Kamchatka River |
| 1 | Chum | 1961 | 1961 | 8050 | W. Kamchatka |
| 1 | Chum | 1961 | 1961 | 8050 | E. Kamchatka |
| 4 | Chum | 1961 | 1961 | 8050 | Sakhalin Island |
| 2 | Chum | 1961 | 1961 | W7052 | E. Kamchatka |
| 3 | Chum | 1961 | 1961 | W7052 | Anadyr River |
| 1 | Chum | 1960 | 1961 | 8050 | Okhotsk Coast |
| 1 | Chum | 1960 | 1961 | W7052 | Okhotsk Coast |
| 1 | Chum | 1959 | 1961 | E 7052 | Okhotsk Coast |
| 1 | Chum | 1959 | 1961 | E 7052 | Sakhalin Island |
| 6 | Pink | 1961 | 1961 | 8050 | Karaginsky area |
| 3 | Pink | 1961 | 1961 | W7052 | Karaginsky area |
| 1 | Pink | 1961 | 1961 | W7052 | U.S.S.R. unknown |

(In addition one pink salmon tagged by the U.S. Bureau of Commercial Fisheries south of Unimak Island was recovered on East Kamchatka).

# SALMON DISTRIBUTION AND ABUNDANCE ON THE HIGH SEAS

by Robert French

This marks the seventh year that United States chartered research vessels have gillnetted salmon on the high seas to determine their distribution and abundance. The primary objectives of the fishing cruises in 1961 were to increase our information of salmon distribution and abundance and to collect whole fish and blood samples for racial studies. Specifically, efforts were made to collect samples from the area of the Japanese mothership salmon fishery in May and June and to gain information on t abundance of the current Bristol Bay red salm run in the eastern Bering Sea during the month June. Fishing was continued south of the Aleuti Islands during July and August to obtain an ind of the abundance of immature red salmon. addition, fishing cruises in the Gulf of Alaska i creased our knowledge of salmon found in that are The stations fished in 1961 are shown in Figure 9.

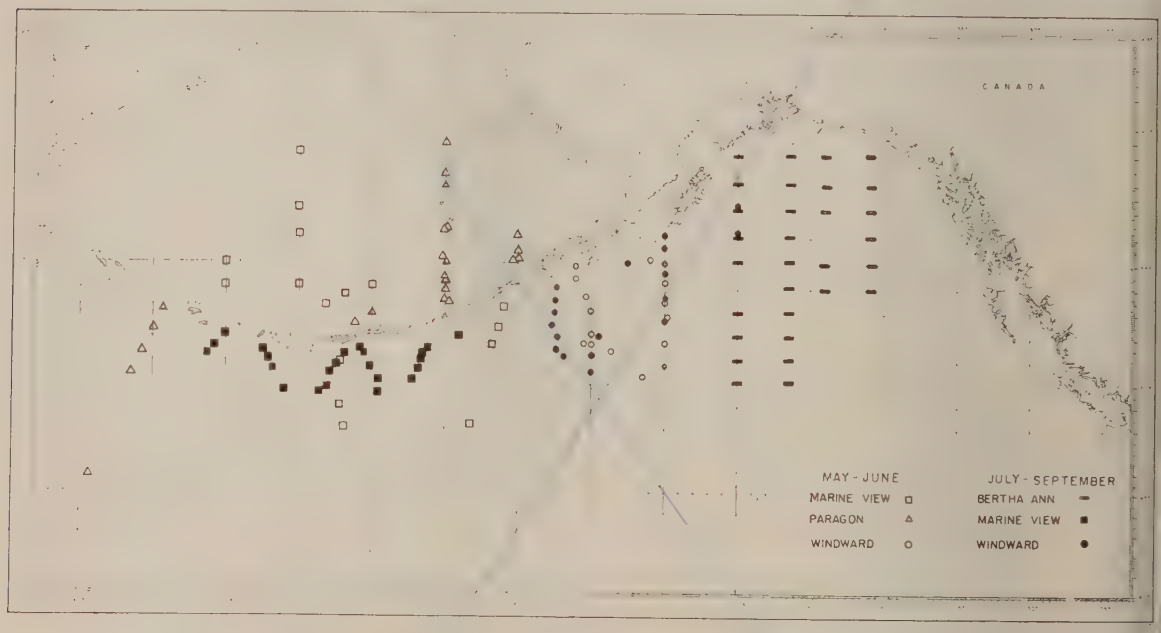


FIGURE 9. Fishing stations of United States research vessels in 1961.

Four gillnet fishing vessels were chartered for the 1961 season. These were the schooner *Paragon*, the seiners *Marine View* and *Windward*, and the *Bertha Ann*, a converted Army refrigerated cargo vessel.

The fishing effort per vessel in 1961 was similar to that of 1959 and 1960 with the exception that four additional shackles of net ($3\frac{7}{8}$-inch mesh) were added to the 36 shackles used the previous two years. The standard for all four vessels in 1961 was thus 40 shackles of net (2,000 fathoms) made up of 24 shackles of $4\frac{1}{2}$-inch mesh and four shackles each of $5\frac{1}{4}$, $3\frac{7}{8}$, $3\frac{1}{4}$, and $2\frac{1}{2}$-inch mesh. The $3\frac{7}{8}$-inch mesh was used in order to fish a more even distribution of mesh sizes thus filling the $1\frac{1}{4}$-inch gap between the $3\frac{1}{4}$ an $4\frac{1}{2}$-inch mesh.

## CATCH DATA

The main feature of the 1961 fishing cruises w the reduced catches of red, chum, and pink salmo Table 9 lists the catches of the four vessels by individu sets and mesh sizes. For ease of comparisons wi other years, catches in the Aleutian area and in t Gulf of Alaska will be reported separately. As past years we have designated May and June as t spring season and July-September as the summ season.

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# On Sea Level, Temperature, and Salinity Variations in the Central Tropical Pacific and on Pacific Ocean Islands[1]

Gunnar I. Roden

*Scripps Institution of Oceanography, La Jolla, California*

*Abstract.* Spectrums of oceanographic and meteorological variables are investigated for the frequency range between zero and six cycles per year. It is found that the root mean square amplitudes of the annual and nonperiodic oscillations are of the same order of magnitude. Sea level changes at neighboring islands are coherent and in phase. Changes at distant islands are coherent only at low frequencies, and their phase depends upon whether the islands are affected by the same wind regime. There is a strong and direct relation between changes of sea level and of sea temperature at low frequencies, but there is no relation between changes of sea level and of atmospheric pressure. Air temperature and sea temperature oscillations are directly related to each other, except where rainfall affects the former, in which case there is no relation. In the intratropical convergence zone a significant and inverse relation exists between air temperature and rainfall. Salinity and rainfall fluctuations are related inversely to each other, but the coherence varies considerably from island to island. Sea temperature and wind speed oscillations are related inversely to each other in the NE trade wind region. The statistical results from the island station analysis are in fair agreement with those obtained from large-scale hydrographic surveys.

*Introduction.* The time changes of oceanographic variables in the tropical Pacific are only little known. Most of the knowledge on this subject before World War II was summarized by *Schott* [1935, 1938]. Since then, there have been studies dealing with special aspects of sea level changes [*Groves,* 1956, 1962; *Pattullo,* 1960] and with results from several large-scale hydrographic surveys [*Austin,* 1963; *Burkov and Ovchinnikov,* 1960; *Dobrovolskii et al.,* 1960; *Reid,* 1961; *Tsuchiya,* 1961].

Continuous records of several oceanographic and meteorological elements have recently become available from Pacific island stations. The U. S. Coast and Geodetic Survey operates seventeen tide stations in the tropical Pacific, where sea level, sea temperature, and salinity are measured regularly. The U. S. Weather Bureau has established eleven first-order meteorological stations, where records of air temperature, rainfall, cloudiness, and, more recently, atmospheric pressure and wind are kept. The material collected by these agencies makes it possible to study the annual and nonperiodic oscillations in more detail than has previously been possible. The approach to be taken herein is mainly a statistical one. In particular, it is desired to investigate by means of spectrum analysis (*a*) whether a significant annual oscillation exists in the tropics; (*b*) whether the oscillations observed on different islands are related; (*c*) whether there is any significant relation among different variables at the same station; and (*d*) whether the statistical findings from island station records are in agreement with those from large-scale hydrographic surveys.

*The data.* The locations of the more important islands and places in the central tropical Pacific are shown in Figure 1. Underlined are the islands on which permanent tide gages have been installed. Not shown are the tide gage stations at Kaneohe Bay, Oahu (just north of Honolulu on the map), and at San Cristobal, Galapagos Islands. The environments of the tide gage and first-order meteorological stations and the year the records were started are summarized in Table 1.

Monthly mean sea levels were obtained from the U. S. Coast and Geodetic Survey (unpublished). They represent the mean of daily averages of 24 hourly observations. The exposure of the tide gage stations is generally adequate, although some gages are located in semienclosed harbors. The accuracy of the monthly mean is about 0.1 cm.

[1] Contribution of the Scripps Institution of Oceanography, New Series.

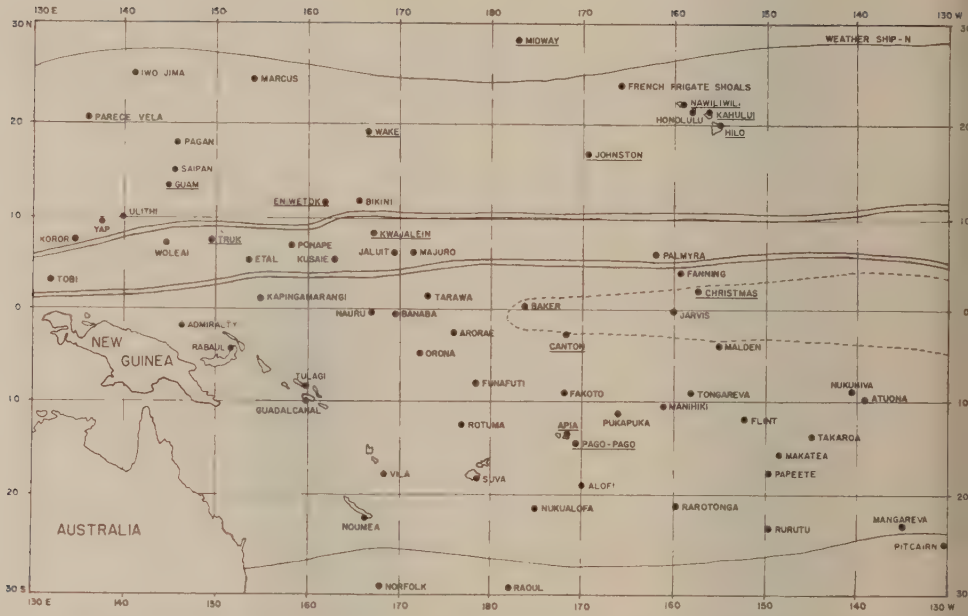



Fig. 1. Important islands and places in the tropical Pacific. Underlined are tide gage stations operated by the U. S. Coast and Geodetic Survey. The dashed line around the equator delineates the equatorial upwelling zone. Stations within the single and the double lines lie in the doldrums, where rainfall is heavy. Stations between the single and the double lines are mostly under the influence of the trade winds. Stations poleward of the single line are, during part of the year, influenced by westerlies.

Monthly mean sea surface temperatures were taken from the U. S. Coast and Geodetic Survey (1956, unpublished). The means represent averages of once-a-day observations, made at a more or less random hour in the vicinity of the tide gage station. Because of the relatively large diurnal temperature range in the tropics, observations made at different hours are not strictly comparable with each other. Although some of the random errors will have canceled out in the monthly mean, the latter should be considered accurate only to within 0.2°C.

Monthly mean salinities, determined by hydrometer, were also obtained from the U. S. Coast and Geodetic Survey (1958, unpublished). The water samples are taken once every day near the tide gage station. No attention is paid to tidal runoff or to any other local effects. The monthly mean is not especially accurate, depending as it does upon the skill of the observer. In most cases it appears to be about 0.1 per mil.

Monthly mean air temperatures, obtaine from the *U. S. Weather Bureau* [1946-196 1956–1961], are *defined* as half the sum of th daily minimum and maximum temperature This rather crude definition is not adequate fc the minimum temperatures in the tropics, whic are mainly caused by evaporation from fallin rain, and may not be representative of the su face conditions [*Riehl*, 1954].

Monthly mean sea level atmospheric pre sures were obtained from the *U. S. Weath Bureau* [1950–1961]. Pressure observations a made four times a day at 0000, 0600, 1200, an 1800 GMT, and the monthly mean is compute from the daily averages. Since the amplitude the pressure variations in the tropics is sma local effects may frequently overshadow syno tic changes. On mountainous islands the pressu difference between the windward and lee sid may amount to 3 mb, while in narrow isla passages a pressure drop of 1 mb is not u common [*Riehl*, 1954]. Nor are atmosphe

TABLE 1. Location and Environment of Tide Gage and First-Order Meteorological Stations in the Tropical Pacific, as of January 1962

| Station | Latitude | Longitude | Island Group | Environment | Record Starts |
|---|---|---|---|---|---|
| **Tide Gage Stations (U. S. Coast and Geodetic Survey)** | | | | | |
| ia | 13°48′S | 171°46′W | Samoan | Reef harbor | 1948 |
| nton | 2°48′S | 171°43′W | Phoenix | Coral atoll | 1949 |
| ristmas | 1°59′N | 157°29′W | Line | Coral atoll | 1956 |
| iwetok | 11°21′N | 162°20′E | Marshall | Coral atoll | 1951 |
| am (Apra) | 13°26′N | 144°39′E | Marianas | Semienclosed harbor | 1948 |
| o, Hawaii | 19°44′N | 155°03′W | Hawaiian | Open bay | 1946 |
| nolulu, Oahu | 21°18′N | 157°52′W | Hawaiian | Semienclosed harbor | 1905 |
| nston | 16°45′N | 169°31′W | Line | Coral atoll | 1950 |
| hului, Maui | 20°54′N | 156°28′W | Hawaiian | Harbor | 1951 |
| neohe (Mokuoloe) | 21°28′N | 157°46′W | Hawaiian | Open bay | 1957 |
| ajalein | 8°44′N | 167°44′E | Marshall | Coral atoll | 1946 |
| dway (Sand) | 28°12′N | 177°22′W | Hawaiian | Atoll | 1947 |
| wiliwili, Kauai | 21°57′N | 159°221′W | Hawaiian | Open bay | 1948 |
| go Pago | 14°17′S | 170°41′W | Samoan | Reef harbor | 1948 |
| ı Cristobal | 0°54′S | 89°36′W | Galapagos | High island | 1952 |
| ık (Moen) | 7°27′N | 151°51′E | Caroline | High island | 1953 |
| ke | 19°17′N | 166°37′E | | Coral atoll | 1950 |
| **First-Order Meteorological Stations (U. S. Weather Bureau)** | | | | | |
| nton | 2°46′S | 171°43′W | Phoenix | Coral atoll | 1949 |
| wetok | 11°21′N | 162°21′E | Marshall | Coral atoll | 1961 |
| am (Taguac) | 13°33′N | 144°50′E | Marianas | High plateau | 1956 |
| o, Hawaii | 19°43′N | 155°04′W | Hawaiian | Airport | 1947 |
| nolulu, Oahu | 21°19′N | 157°52′W | Hawaiian | Airport | 1946 |
| nston | 16°44′N | 169°31′W | Line | Coral atoll | 1958 |
| ror | 7°20′N | 134°29′E | Palau | Hilly island | 1955 |
| ajalein | 8°44′N | 167°44′E | Marshall | Coral atoll | 1961 |
| ue, Kauai | 2.°59′N | 159°21′W | Hawaiian | Airport | 1951 |
| juro | 7°05′N | 171°23′E | Marshall | Coral atoll | 1955 |
| ape | 6°58′N | 158°13′E | Caroline | High island | 1951 |
| k (Moen) | 7°28′N | 151°51′E | Caroline | High island | 1951 |
| ke | 19°17′N | 166°39′E | | Coral atoll | 1948 |
| ) | 9°31′N | 138°08′E | Caroline | Grass-covered hills | 1951 |

ssure readings during heavy showers repre-tative of the surface environment, according he same author. Considering all these error rces, the monthly mean atmospheric pressure robably accurate only to within about 0.2 mb. Ionthly total precipitation was obtained from *U. S. Weather Bureau* [1946–1961, 1956–1]. The accuracy of the total depends upon amount of rain and the exposure of the rain e; a rough estimate is 10 per cent of the l.

he available wind records, with a few excep-s, do not extend sufficiently far into the for the purposes of this analysis. Most wind d observations on atolls were begun after 5 by the U. S. Weather Bureau. The monthly means are computed from the hourly wind speed values; no attention is paid to the wind direction in the calculation of the mean speed. The directions are reported to 16 compass points. Most wind records from mountainous islands are not representative of oceanic conditions.

*Diurnal and local environmental variations.* An interesting study of diurnal temperature and salinity variations in the Palau Islands was made by *Matsuya* [1937], whose findings are given in Table 2. It is seen that the temperature range of the sea surface varies between 0.9°C and 1.3°C, depending upon the environment. The highest temperatures occur in the early afternoon and the lowest occur in the early morning. Where the water is in open communication

with the ocean, a weak secondary maximum occurs during the nighttime low tide. This may be caused by seaward transport of bay water heated during the day. The diurnal air temperature range varies between 3.7°C and 4.3°C and is only slightly dependent upon the environment. It is of interest to note that recent investigations on Eniwetok atoll [*Blumenst et al.*, 1959] have yielded similar results.

The diurnal variations of (titrated) salin are also given in Table 2. The range is v dependent upon the local environment, be largest in the deep tide-pool (0.50 per mil) smallest in the open anchorage where ocea

TABLE 2. Diurnal Change of Sea Temperature, Air Temperature, Salinity, and Oxygen at the Surface and at the Bottom in Iwayama Bay (Zogeal Bay), Palau Islands [*Matsuya*, 1937]

| Local Time | Sea Temp., °C | | Air Temp., °C | Salinity, per mil | | Dis. Oxygen, ml/l | |
|---|---|---|---|---|---|---|---|
| | Surface | Bottom | | Surface | Bottom | Surface | Bottom |
| March 7–8, 1935. Large tide pool, 100 m diameter, 13 m deep, isolated at low tide. | | | | | | | |
| 1200 | 29.2 | 29.0 | 30.3 | 33.46 | 33.60 | 3.8 | 3.7 |
| 1400 | 29.8 | 29.0 | 30.1 | 33.46 | 33.60 | 4.7 | 3.8 |
| 1500 L* | 29.7 | 29.0 | 30.0 | 33.31 | 33.60 | 4.5 | 3.8 |
| 1620 | 29.7 | 29.0 | 29.5 | 33.17 | 33.60 | 4.3 | 3.7 |
| 1820 | 29.3 | 28.9 | 27.8 | 33.31 | 33.69 | 4.5 | 3.7 |
| 2035 H | 29.0 | 29.0 | 27.6 | 33.64 | 33.74 | 3.9 | 3.8 |
| 2230 | 29.0 | 29.0 | 27.3 | 33.60 | 33.69 | 3.8 | 3.9 |
| 0030 | 28.9 | 29.0 | 26.4 | 33.48 | 33.72 | 3.8 | 3.8 |
| 0300 L | 28.9 | 29.0 | 26.1 | 33.46 | 33.72 | 3.6 | 3.8 |
| 0450 | 28.7 | 28.9 | 26.0 | 33.49 | 33.64 | 3.6 | 3.7 |
| 0630 | 28.5 | 28.7 | 26.6 | 33.53 | 33.60 | 3.5 | 3.4 |
| 0820 H | 28.7 | 28.8 | 27.6 | 33.67 | 33.67 | 3.6 | 3.7 |
| 1000 | 28.8 | 28.5 | 28.5 | 33.67 | 33.74 | 3.7 | 3.6 |
| Range | 1.3 | 0.5 | 4.3 | 0.50 | 0.14 | 1.2 | 0.5 |
| March 23–24, 1935. Open anchorage, depth 25 m, oceanic conditions. | | | | | | | |
| 1013 | 29.1 | 28.5 | 30.7 | 34.29 | 34.33 | 4.2 | 4.0 |
| 1240 | 29.3 | 28.7 | 30.7 | 34.27 | 34.29 | 4.6 | 3.9 |
| 1440 L | 29.8 | 28.9 | 30.5 | 34.27 | 34.27 | 4.4 | 4.1 |
| 1630 | 29.7 | 28.9 | 29.5 | 34.27 | 34.30 | 4.4 | 4.1 |
| 1930 | 28.9 | 28.7 | 27.3 | 34.27 | 34.30 | 4.2 | 4.1 |
| 2115 H | 29.0 | 28.7 | 27.3 | 34.29 | 34.30 | 4.2 | 4.1 |
| 2315 | 28.8 | 28.6 | 27.3 | 34.30 | 34.29 | 4.2 | 4.1 |
| 0120 | 28.8 | 28.8 | 26.9 | 34.27 | 34.27 | 3.9 | 3.9 |
| 0325 L | 28.9 | 28.8 | 26.7 | 34.23 | 34.27 | 3.7 | 3.8 |
| 0525 | 28.7 | 28.7 | 26.9 | 34.27 | 34.27 | 3.9 | 3.9 |
| 0655 | 28.6 | 28.6 | 27.5 | 34.27 | 34.34 | 3.9 | 3.9 |
| 0855 H | 28.8 | 28.6 | 29.5 | 34.29 | 34.30 | 3.9 | 3.9 |
| Range | 1.2 | 0.4 | 4.0 | 0.07 | 0.07 | 0.9 | 0.2 |
| Jan. 19–20, 1935. Bay entrance, open passage, depth 10 m. | | | | | | | |
| 1020 | 27.9 | 28.3 | 29.3 | 33.74 | 33.68 | 4.1 | 3.9 |
| 1150 | 28.6 | 28.4 | 29.5 | 33.65 | 33.80 | 4.2 | 3.9 |
| 1400 L | 28.8 | 28.8 | 29.0 | 33.62 | 33.65 | 4.1 | 4.1 |
| 1600 | 28.5 | 28.4 | 28.3 | 33.84 | 33.71 | 4.4 | 4.3 |
| 1800 H | 28.4 | 28.2 | 27.3 | 33.82 | 33.74 | 4.3 | 4.3 |
| 2045 | 28.6 | 28.3 | 26.0 | 33.89 | 33.80 | 4.8 | 4.2 |
| 2240 | 28.2 | 28.4 | 25.8 | 33.74 | 33.69 | | |
| 0300 L | 28.5 | 28.5 | 25.8 | 33.62 | 33.62 | 4.1 | 4.1 |
| 0715 H | 28.2 | 28.2 | 26.8 | 33.74 | 33.74 | 4.0 | 4.1 |
| Range | 0.9 | 0.6 | 3.7 | 0.22 | 0.18 | 0.8 | 0.5 |

* H is high tide, L is low tide.

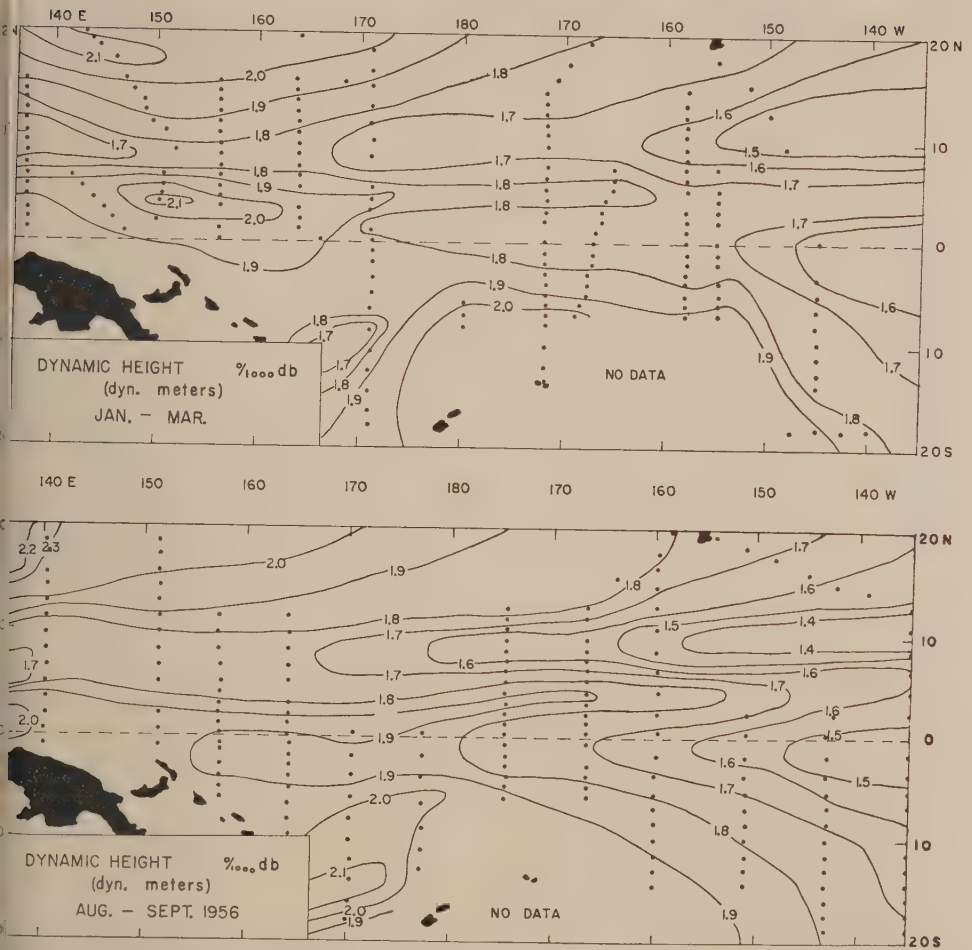



Fig. 2. Dynamic height relative to the 1000–db surface in the central tropical Pacific. Dots indicate station positions. The contour interval is 0.1 dynamic meter.

itions prevail (0.07 per mil). There is some ndence upon the tide: low tide carries low- ity bay water seaward, and high tide carries -salinity oceanic water shoreward. This t is probably limited to high islands where all is abundant and where there is runoff; lat atolls the diurnal salinity variation is to be less.

ıe diurnal variation of dissolved oxygen ıle 2) varies between 0.8 ml/l and 1.2 ml/l e sea surface. It is larger than could be ex- ed by the diurnal temperature variation is probably due to biological activity.

*e areal distribution of dynamic height, sea erature, and salinity in the central tropical Pacific.* The dynamic height topography relative to the 1000–db surface is shown in Figure 2. The charts were prepared from material collected by the Equapac expedition of 1956 (Oceanic Observations of the Pacific, unpublished), the Maritime Safety Agency of Japan (1954, 1955), and the *U. S. Bureau of Commercial Fisheries* [1954, 1957]. The outstanding features are the two troughs, one around the equator and the other approximately between latitudes 8°N and 12°N, and the general increase in sea level toward the west, features which are in good agreement with a composite dynamic height chart prepared earlier by *Reid* [1961]. There is, however, a recognizable change

TABLE 3. Root Mean Square (rms) Amplitudes of the Annual and Nonperiodic Oscillations of Level ($Z$), Sea Surface Temperature ($\theta$), Air Temperature ($A$), Salinity ($S$), Rainfall ($R$), and Atmospheric Pressure ($P$). Also Given is the Maximum Departure from the Monthly Mean.

| | Annual Oscillation (rms) | | | | | | Nonperiodic Oscillation (rms) | | | | | | Maximum Departu | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | $Z$, cm | $\theta$, °C | $A$, °C | $S$, ‰ | $R$, cm | $P$, mb | $Z$, cm | $\theta$, °C | $A$, °C | $S$, ‰ | $R$, cm | $P$, mb | $Z$, cm | $\theta$, °C | $A$, °C | $S$, ‰ | $R$, cm |
| Apia | 5.5 | 0.9 | 0.8 | 0.6 | 15.8 | 1.2 | 5.2 | 0.5 | 0.6 | 0.6 | 12.3 | 0.7 | 16 | 1.2 | 1.0 | 1.5 | 14 |
| Canton | 4.2 | 0.8 | 0.6 | 0.3 | 7.5 | 0.8 | 2.9 | 0.8 | 0.5 | 0.3 | 7.4 | 0.6 | 13 | 1.1 | 1.1 | 1.0 | 21 |
| Christmas | 5.1 | 1.0 | | 1.2 | | | 3.8 | 1.0 | | 1.2 | | | 11 | 2.1 | | 5.2 | |
| Eniwetok | 5.0 | 0.8 | 0.5 | | 9.6 | | 4.3 | 0.5 | 0.4 | | 6.6 | | 12 | 1.5 | 1.1 | | 22 |
| Guam | 6.8 | 0.9 | 1.1 | 0.5 | 15.4 | | 5.4 | 0.5 | 0.7 | 0.4 | 10.4 | | 18 | 1.5 | 1.1 | 1.4 | 40 |
| Hilo | 5.3 | 0.8 | 1.1 | 1.7 | 19.1 | 1.5 | 4.5 | 0.5 | 0.5 | 1.5 | 16.7 | 1.3 | 15 | 2.4 | 1.2 | 4.2 | 60 |
| Honolulu | 6.5 | 1.1 | 1.5 | 0.6 | 8.5 | 1.3 | 4.8 | 0.5 | 0.5 | 0.6 | 7.6 | 1.1 | 16 | 1.2 | 1.4 | 2.2 | 26 |
| Johnston | 8.1 | 1.0 | 1.1 | 0.4 | 6.8 | | 5.1 | 0.5 | 0.5 | 0.3 | 6.2 | | 12 | 1.0 | 1.2 | 1.1 | 26 |
| Kahului | 5.6 | | 1.4 | | 7.1 | | 4.6 | | 0.5 | | 5.6 | | 15 | | 1.2 | | |
| Kwajalein | 5.6 | 0.8 | 0.6 | 0.5 | 12.3 | | 5.0 | 0.5 | 0.5 | 0.4 | 8.9 | | 19 | 1.6 | 1.6 | 1.0 | 23 |
| Midway | 6.5 | 2.7 | 2.9 | 0.4 | 6.7 | 2.4 | 5.1 | 0.7 | 0.6 | 0.4 | 6.1 | 2.0 | 19 | 1.7 | 2.2 | 0.8 | 19 |
| Nawiliwili | 5.6 | | | | | 1.6 | 4.0 | | | | | 1.1 | 11 | | | | |
| Pago Pago | 5.8 | 0.8 | | 0.6 | | | 5.6 | 0.5 | | 0.6 | | | 17 | 1.2 | | 1.4 | |
| Truk | 7.6 | 0.7 | 0.3 | 0.6 | 13.5 | 0.8 | 7.3 | 0.5 | 0.3 | 0.5 | 10.9 | 0.6 | 21 | 1.0 | 0.8 | 2.0 | 60 |
| Wake | 7.5 | 1.6 | 1.3 | 0.5 | 6.1 | 1.4 | 7.1 | 0.6 | 0.5 | 0.4 | 4.7 | 0.9 | 23 | 1.7 | 1.1 | 1.1 | 19 |

in dynamic height from February to August. In the troughs the dynamic height has decreased by approximately 10 dynamic cm (1 dynamic cm $= 10^3$ cm$^2$ sec$^{-2}$), while in the northwestern part of the region and east of the Solomon islands it appears to have increased between 10 and 20 dynamic cm. Since the dynamic height divided by gravity is an approximate indicator of sea level (if the hydrostatic equation can be assumed to hold), the order of magnitude of the seasonal sea level change is 15 cm. This value is in fair agreement with twice the rms amplitude of the observed annual sea level oscillation at island stations (see Table 3).

The areal distribution of sea surface temperature in the central tropical Pacific is shown in Figure 3. The charts were prepared from summaries for 1° × 1° areas prepared by the Hydrographic Office (unpublished). It is seen that there is a tongue of low temperatures around the equator, which extends to about longitude 170°E in February and to about longitude 170°W in August. At approximately 7°N and 10°S, tongues of warm water extend eastward. The seasonal temperature variation between latitudes 10°S and 10°N is usually small, rarely exceeding 1°C. Large seasonal changes occur in the Coral Sea and in the northwestern part of the region considered. The temperature difference between February and August agrees well with twice the rms am tude of the annual temperature variation island stations (Table 3).

The salinity and rainfall distributions shown in Figure 4. The salinities were obtai from the same sources as the dynamic heig (see above). The rainfall totals were taken fr *U. S. Weather Bureau* [1956–1961, 1959] p lications and *Schott* [1938] and refer to servations made on islands. Only flat islands atolls were used in preparing the rainfall ch in Figure 4.

An examination of the salinity charts bri out the following interesting features: (*a*) salinity distribution is asymmetric with res to the equator. (*b*) The low-salinity belt n of the equator coincides roughly with the r doldrum belt. (*c*) The highest salinities do occur in the equatorial dry zone, where rai is least; they occur instead in the southeas part of the region, where rainfall is more abu ant. (*d*) The order of magnitude of the sali change from February to August is 0.3 per over large parts of the region, though it ma larger locally.

*The records.* Records of sea level anom are shown in Figure 5. The anomalies were tained by taking differences between the mon means and the long-term means for the s months. It was necessary to eliminate the

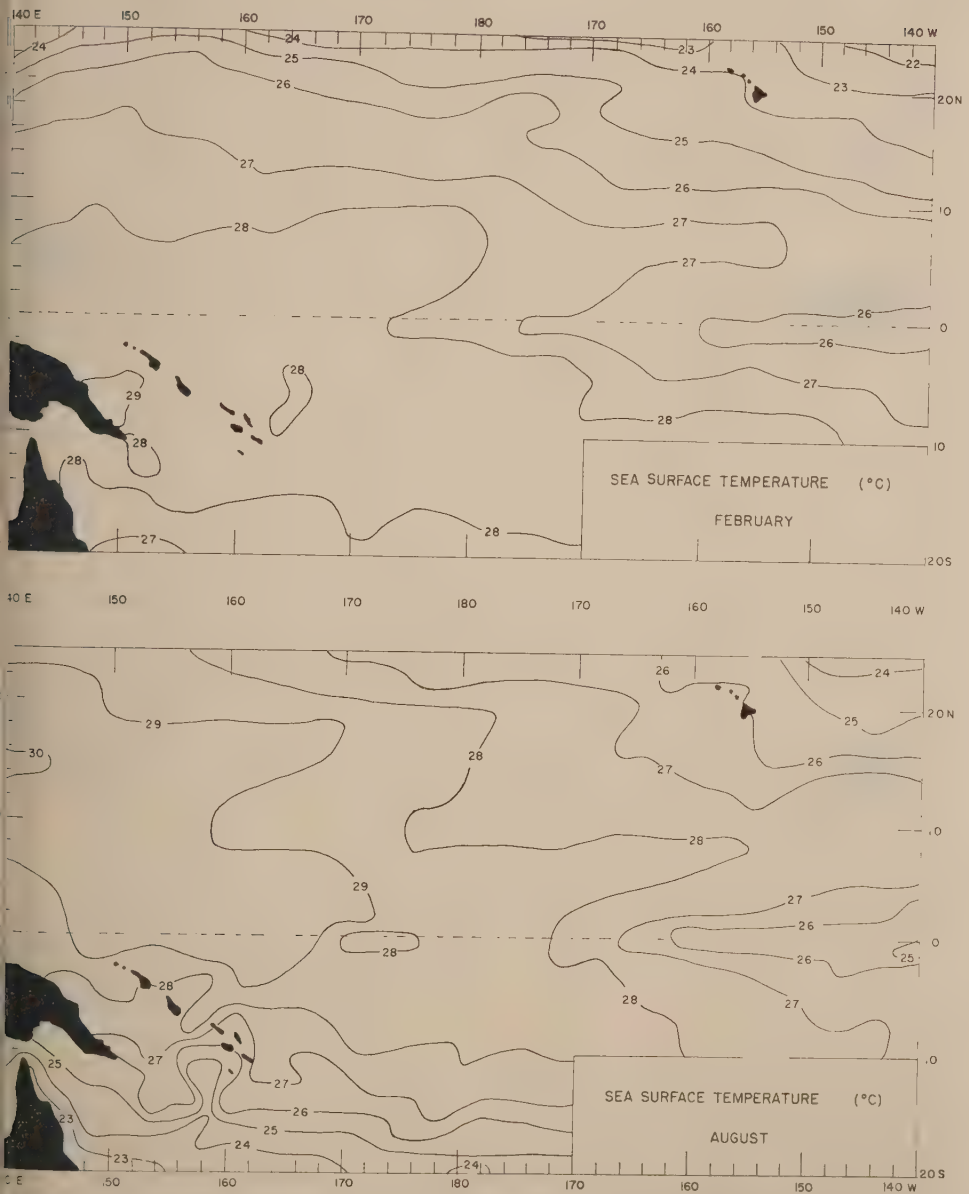



Fig. 3. Sea surface temperatures in the central tropical Pacific. Based on averages over 1° × 1° rectangles obtained from the U. S. Hydrographic Office (unpublished).

l cycle in order to make records from differ- islands comparable. It is seen that the mean litude of the sea level anomalies varies be- en 5 cm and 10 cm and that the amplitude of maximum departures is near 20 cm. There certain similarity among sea level records for the Hawaiian group and among those for the Samoan and Micronesian groups. Between the two groups certain differences occur—for example, the sign of the large anomalies in 1955 and 1958.

Records of sea surface temperature anomalies

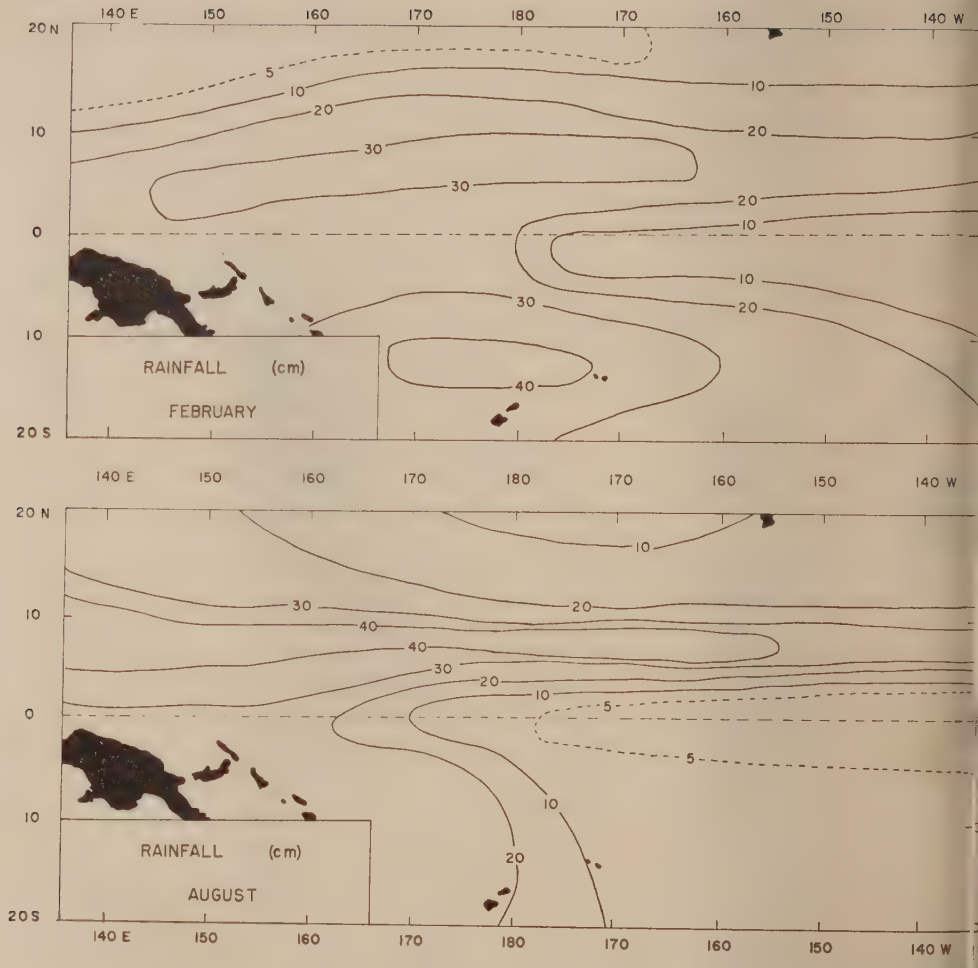
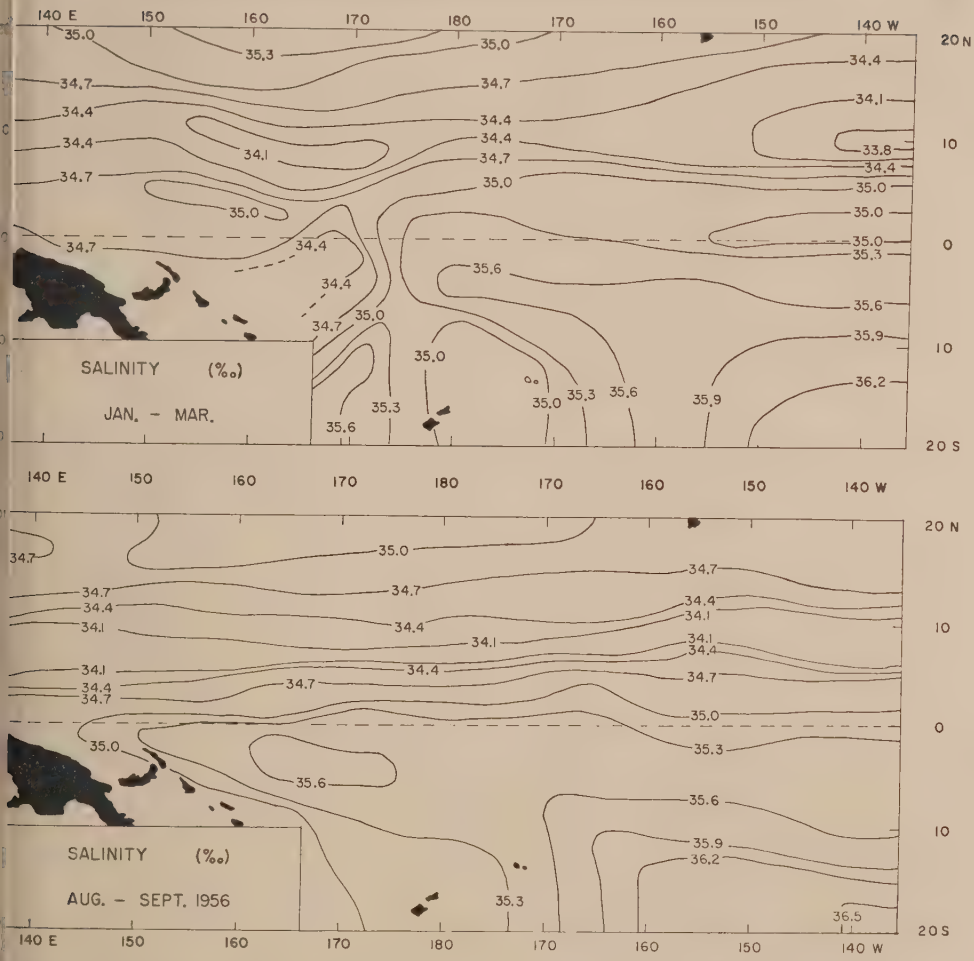



Fig. 4. *Left.* Sea surface salinities in
the same as that shown in Figure 1. *R*
tions made on small atolls and low islands
tentative.

are shown in Figure 6. The outstanding feature is the large amplitude of the temperature anomalies at Canton and Christmas islands in comparison with some anomalies at other islands. It may be due to the fact that Canton and Christmas islands are located near the boundary between the zone of equatorial upwelling and the region of tropical warm water (Figures 1 and 3). The temperature anomalies at these two stations are remarkably persistent. They seem to indicate a 4-year regularity, but whether the latter is a periodicity in the mathematical sense cannot be ascertained from such a sh
period of record. The temperature oscillati
at Truk and Guam appear to be similar, altho
very few features common to the other rec
are observed.

*The root mean square amplitudes of the
nual and nonperiodic oscillations.* The rms
plitudes and the amplitude of the maximum
parture from the monthly mean are given
Table 3. For sea level, there is very little
ference between the amplitudes of the an
and nonperiodic oscillations. For sea and




l tropical Pacific. The station coverage is rainfall amounts obtained from observa- olations over ocean regions are only

peratures, this difference is large only for ıds located a considerable distance from the ıtor (Midway, Wake, the Hawaiian Islands). same is approximately true of atmospheric sure. For salinity and precipitation, the dif- nce is usually small. Typical rms amplitudes he annual cycle are: sea level, 4 to 8 cm; and air temperature, 0.5° to 1.5°C; atmos- ric pressure, 0.8 to 1.6 mb; salinity 0.3 to 1.7 mil; and rainfall 6 to 19 cm. Those of the periodic oscillations are approximately within same limits, except for temperature, for ch the range is slightly less.

Characteristic maximum departures from the monthly means are about three times the rms amplitude of the nonperiodic oscillations.

*The statistical analysis.* Power spectrums were computed for fifteen island stations. The number of observations at each island, $n$, and the number of estimates of spectrums used in the calculations, $m$, are given in Table 4. The reliability of the calculations is indicated by the *degrees of freedom,* defined by $\nu = 2n/m$. The calculations were done for frequencies between 0 and 6 cycles per year (cpy), the upper limit being determined by twice the sampling fre-

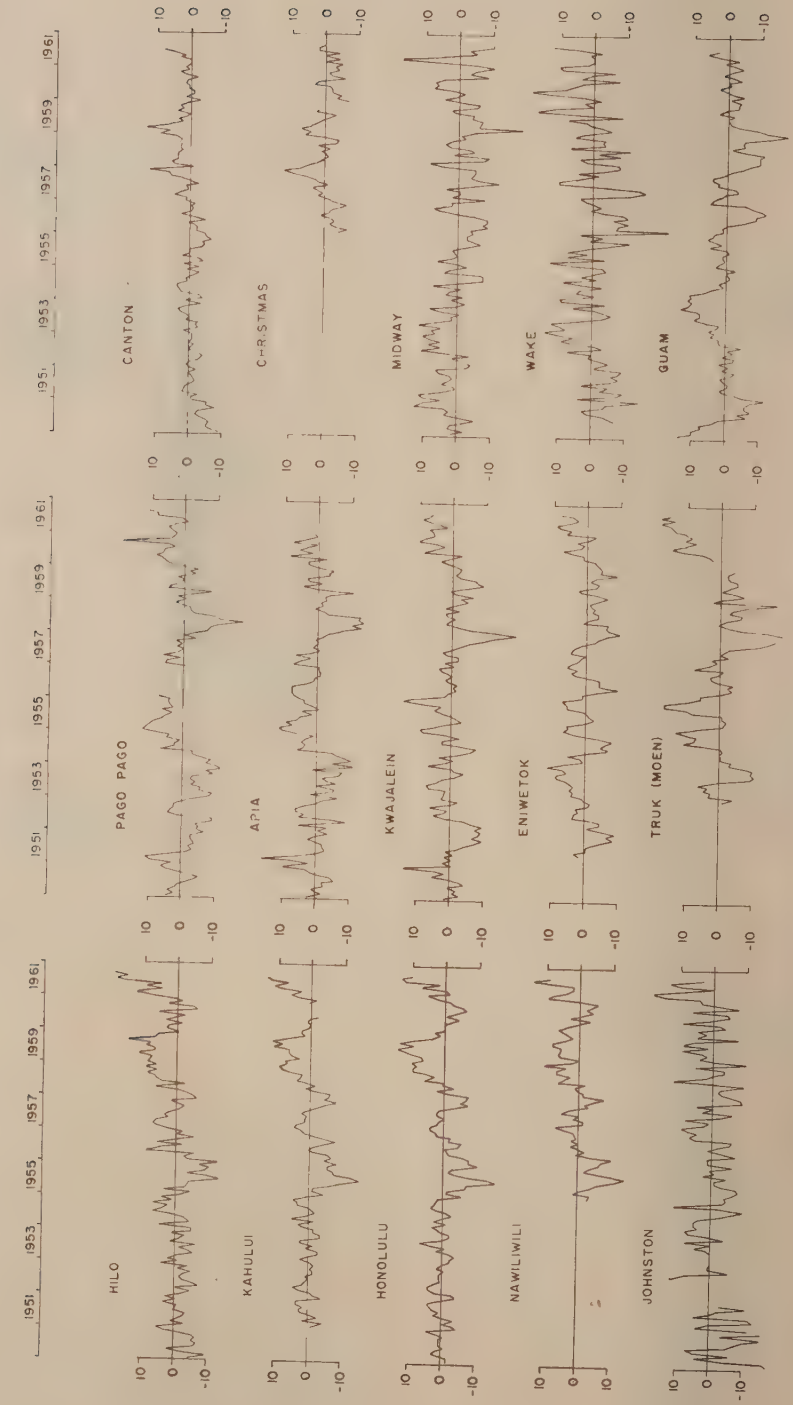



Fig. 5. Sea level anomalies from the long-term monthly means at Pacific island stations.

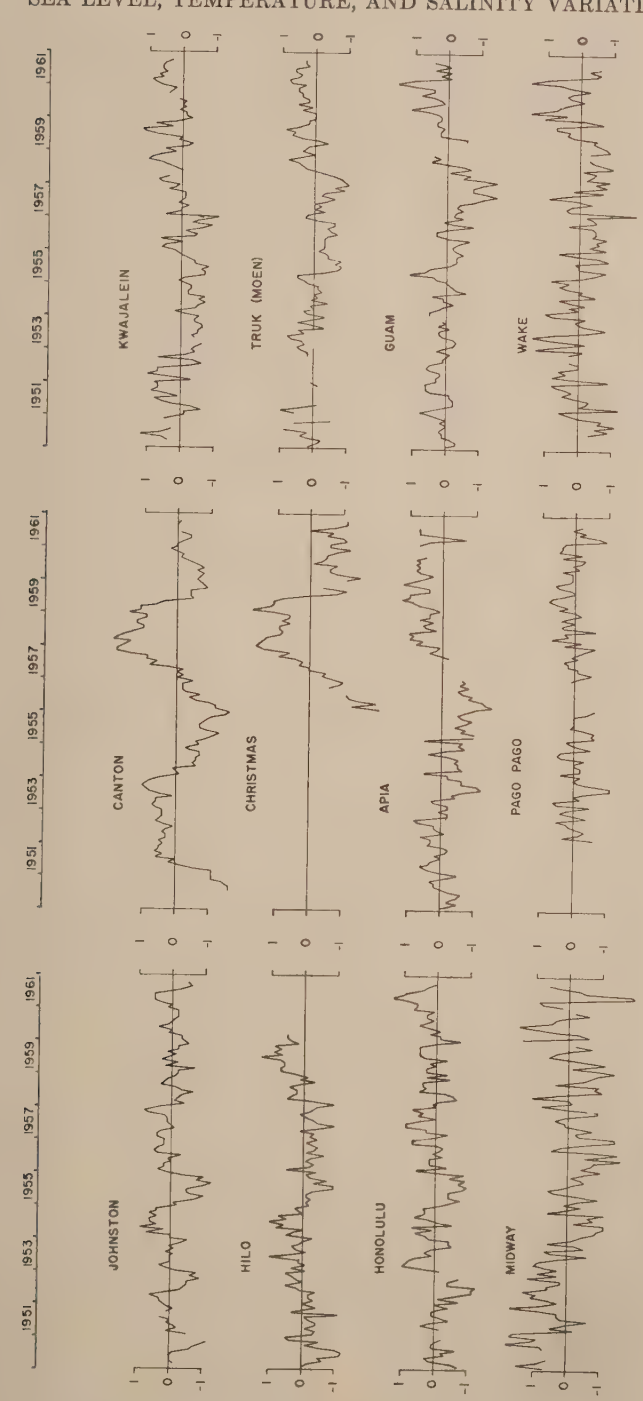



Fig. 6. Sea temperature anomalies from the long-term monthly means at Pacific island stations.

TABLE 4. Number of Observations, $n$, Number of Spectrum Estimates, $m$, and Number of *Degrees of Freedom*, $\nu$, Used in the Spectrum Analysis

| Station | $n$ | $m$ | $\nu$ |
|---|---|---|---|
| Apia | 144 | 12 | 24 |
| Canton | 120 | 12 | 20 |
| Christmas | 60 | 12 | 10 |
| Eniwetok | 108 | 12 | 18 |
| Guam | 144 | 12 | 24 |
| Hilo | 120 | 12 | 20 |
| Honolulu | 192 | 12 | 32 |
| Johnston | 96 | 12 | 16 |
| Kahului | 120 | 12 | 20 |
| Kwajalein | 144 | 12 | 24 |
| Midway | 120 | 12 | 20 |
| Nawiliwili | 60 | 12 | 10 |
| Pago Pago | 144 | 12 | 24 |
| Truk | 96 | 12 | 16 |
| Wake | 120 | 12 | 20 |

quency. In view of the relatively short time span of the records, only twelve spectrum estimates were computed for each time series. In the computations, methods developed by *Blackman and Tukey* [1958] were applied.

The power-spectrum densities are shown in Figure 7, in which the ordinate is on a logarithmic scale and has the dimensions of amplitude squared per cycle per year. The thin vertical lines refer to the 95 per cent confidence limits. The black circles refer to the original records, and the crosses refer to those from which the annual variation has been eliminated.

The sea level spectrums show that most of the power of the oscillations is concentrated at low frequencies. With increasing frequency, the power decreases, until the level of environmental noise is reached. The latter varies from station to station, being least (0.5 cm) at Truk and highest (3.0 cm) at Wake. The fact that there are no significant peaks in the spectrums indicates the absence of periodicities, including that of the annual cycle.

The spectrums of sea surface and air temperatures show the expected results, i.e. that the importance of the annual cyle increases with distance from the equator. The annual cycle is least pronounced at Canton (2°S) and most pronounced at Wake (19°N) and at Honolulu (21°N). The level of environmental background noise appears to be close to 0.1°C.

The spectrums of salinity are somewhat more variable. If the stations are located on s islands, the power decreases fairly rapidly increasing frequency until the environme noise level (about 0.1 per mil) is reached. If stations are in semienclosed harbors (Honolu most of the fluctuations appear to be due random noise. The annual cycle is not evi from the spectrums.

The power spectrums of rainfall indicate t on most islands the fluctuations are rand there being little dependence upon freque and no annual cycle.

The power spectrums of atmospheric p sure show that the annual cycle is more p nounced at higher latitudes (Wake Island) t near the equator (Canton Island). The envir mental noise level varies between about 0.1 at Canton and Truk and about 0.3 mb at Wa

The statistical relation between two reco is expressed by the coherence and phase. T coherence indicates best the phase correlati differing from the ordinary correlation coeffici by being always positive. For an infinitely l record, the coherence equals zero if there is linear relation, and 1 if the relation is perf For a finite record, the 95 per cent confide limit is given by $(4/\nu)^{1/2}$, and the coherence unrelated records tends to scatter around $(2/\nu)$ according to Tukey (G. W. Groves, perso communication). The phase indicates the ti displacement of one record relative to the ot and also whether the variables are related rectly or inversely to each other when there no time lag. Since the interpretation of the ph is not unique, reference must be made to physical aspects of the problem. A rough e mate of the 95 per cent confidence limit is gi by *Munk et al.* [1959].

*Coherence and phase of sea level oscillation different islands* (*Figure 8*). A visual inspect of the sea level records shown in Figure 5 s gests that the oscillations are coherent over c siderable distances. The same result is obtai if the coherence and phase spectrums are co puted. If the distance between the islands short, as between Kahului (Maui) and Ho lulu (Oahu) and between Apia (Upolu) Pago Pago (Tutuila), the coherence is sig cant at all frequencies between 0 and 6 and the oscillations are in phase. If the dista between the islands is large, the coherenc significant only at low frequencies. The phas

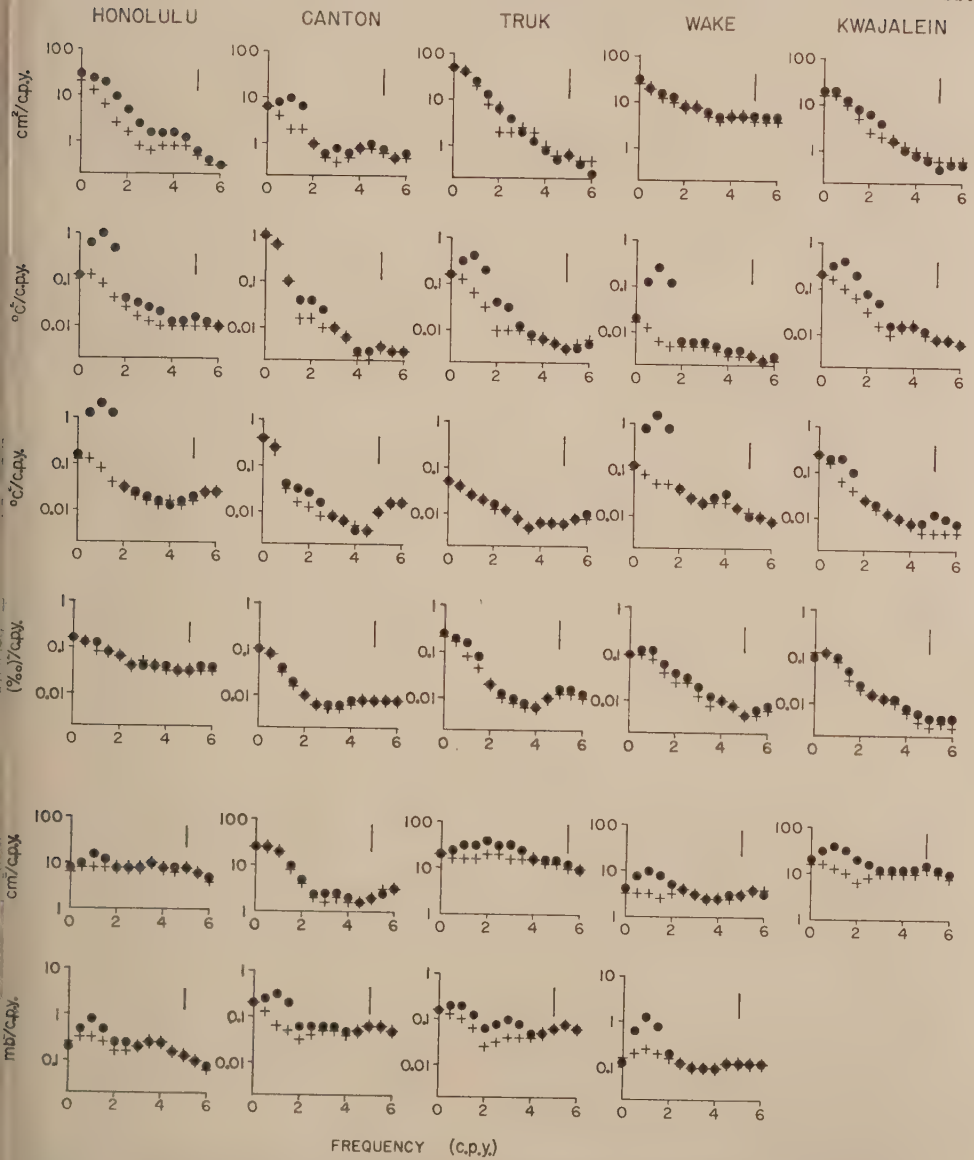



Fig. 7. Power spectrums of oceanographic and meteorological variables as a function of frequency. The solid circles refer to the original records, the crosses to those from which the annual cycle was eliminated. The vertical line denotes the 95 per cent confidence limits for the spectrums. Note that the ordinate is on a logarithmic scale.

significant part of the spectrum is 0° if the nds are affected by the same wind regime, the pairs Canton-Christmas (equatorial terlies), Kahului-Johnston (NE trades), ajalein-Truk (NE trades), and Kwajalein-wetok (NE trades). If the islands are not affected by the same wind regime, the phase relation becomes more complicated. An interesting example is furnished by the station pair Canton–Pago Pago (Canton being in the region of the equatorial easterlies and Pago Pago being in the SE trade wind region). The phase in the

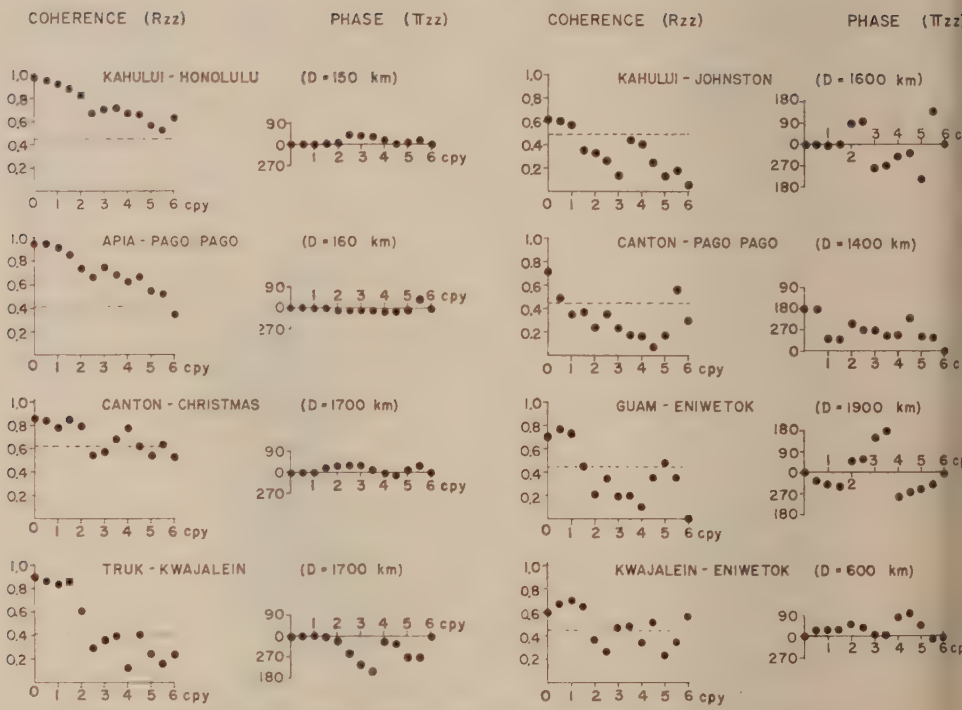

COHERENCE (Rzz)
PHASE (Tzz)
COHERENCE (Rzz)
PHASE (Tzz)
KAHULUI - HONOLULU (D = 150 km)
KAHULUI - JOHNSTON (D = 1600 km)
APIA - PAGO PAGO (D = 160 km)
CANTON - PAGO PAGO (D = 1400 km)
CANTON - CHRISTMAS (D = 1700 km)
GUAM - ENIWETOK (D = 1900 km)
TRUK - KWAJALEIN (D = 1700 km)
KWAJALEIN - ENIWETOK (D = 600 km)
cpy

Fig. 8. Coherence and phase of sea level oscillations at different islands. *D* denotes shortest distance.

significant part of the spectrum is 180°, which indicates that the sea level oscillations at the two places are out of phase. The physical processes leading to the 180° phase difference are not clearly understood at present.

*Coherence and phase between sea level and atmospheric pressure (not shown).* In higher latitudes, sea level oscillations closely follow those of atmospheric pressure. With decreasing latitude, the relation between these two variables becomes less and less significant. At latitude 50°N about 70 per cent of the variables were found to be related; at latitude 20°N this percentage decreased to about 15 per cent [*Roden,* 1960]. It is therefore not surprising that in the five coherence spectrums investigated (Honolulu, Hilo, Canton, Truk, and Wake) almost no significant relation occurred between sea level and atmospheric pressure oscillations.

*Coherence and phase between sea level and sea temperature (Figure 9, left).* The coherence and phase between sea level and sea temperature depend largely upon the local environment. It is highly significant at Canton and Christmas islands, which are near the boundar between the zone of equatorial upwelling a the region of tropical warm water. At Christm Island almost 64 per cent of the sea level oscill tions are related to those of sea temperature f frequencies between 0 and 2 cpy. At Hilo, the windward side of the island of Hawaii, abo 30 per cent of the variables are related to ea other in the frequency range between 0 and cpy. At Midway and Wake, which are sm atolls in relatively high tropical latitudes, th is good coherence only at very low frequenci It should be noted that no significant relati between sea level and sea temperature has be found at tide stations in semienclosed harbo such as Honolulu, Guam (Apra), Pago Pago, a Apia (not shown).

*Coherence and phase between sea level a wind (not shown).* Unfortunately, a thorou analysis of this coherence and phase was ma impossible by the lack of suitable wind reco The relation was investigated only for W Island. It was found that at low frequencies th was a barely significant and inverse relation

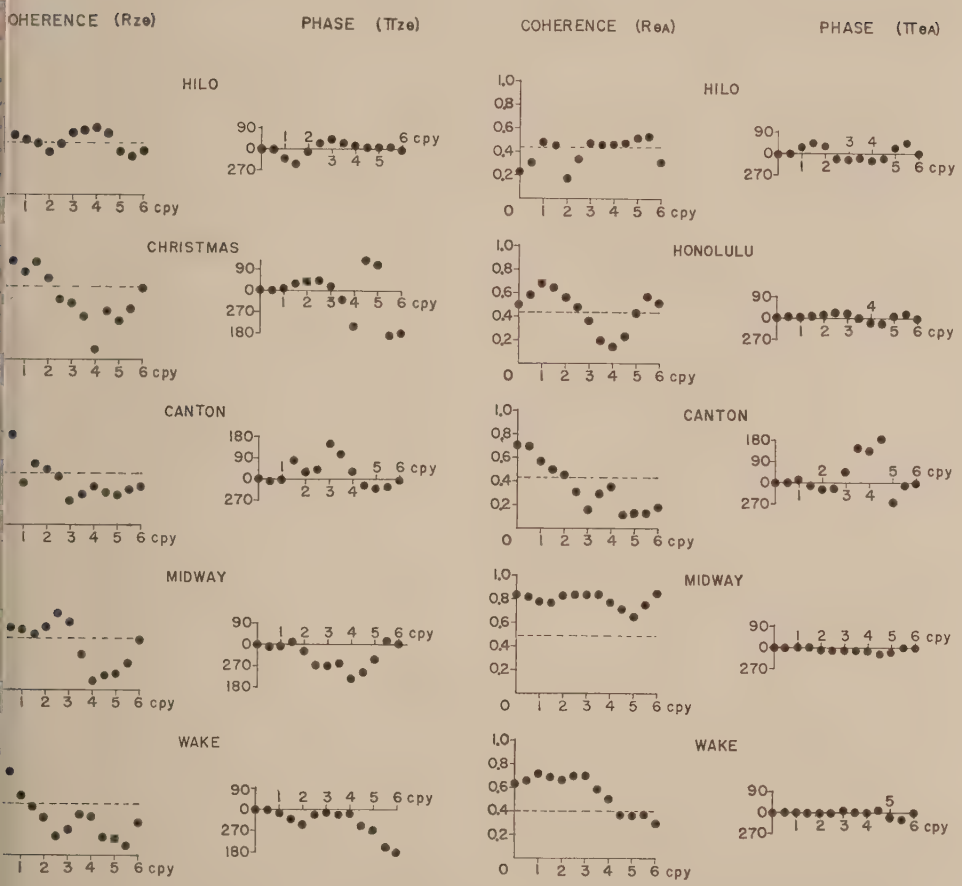



Fig. 9. *Left.* Coherence and phase between anomalies of sea level and sea surface temperature. *Right.* Coherence and phase between anomalies of sea surface temperature and air temperature. The dashed line refers to the 95 per cent confidence limits.

en sea level and the NE wind. In a previous stigation *Groves* [1962] showed that at ton Island there was some relation between level and the south wind component.

*oherence and phase between sea tempera- and wind* (*Figure 10*). Owing to the lack of able wind records, the computations were e only for Wake Island. Significant coherence ound at all frequencies between 0 and 6 cpy, re about 36 per cent of the sea temperature llations are inversely related to those of the trade wind. A similar result was obtained by *len* [1962] for NE trade wind region of the antic.

*oherence and phase between sea and air perature* (*Figure 9, right*). Significant coherence between sea and air temperatures is found only for those islands and those frequencies for which the air temperature is not markedly affected by rainfall, for islands in relatively high tropical latitudes or in the equatorial dry zone. The best coherence is found at Midway, a small and rather dry atoll. Here, about 64 per cent of the variables are related directly to each other at all frequencies between 0 and 6 cpy. At most other islands the coherence is better at lower than at higher frequencies. It is noteworthy that no relation between sea and air temperatures was found at islands in the intertropical convergence zone, where rainfall is abundant.

*Coherence and phase between sea tempera-*

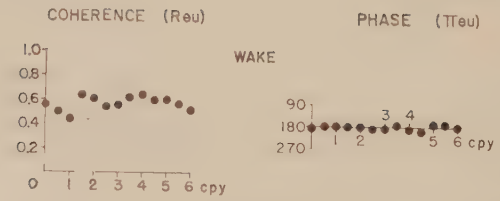



Fig. 10. Coherence and phase between anomalies of sea surface temperature and wind speed. The dashed line refers to the 95 per cent confidence limits.

*ture and rainfall (not shown)*. In general, no significant relation between sea temperature and rainfall oscillations was found. An exception is Canton Island, where at very low frequencies sea temperature and rainfall are directly related. We can expect a similar relation at Christmas Island (owing to its proximity to the boundary between the warm and rainy doldrums and the cool and dry equatorial upwelling zone), although no spectrums could be computed because of the lack of rainfall records.

*Coherence and phase between air temperature and rainfall (Figure 11, left)*. Significant coherence between air temperature and rainfall is found in the intertropical convergence zone and in adjacent areas. At Canton and Kwajalein the coherence in the significant part of the spectrum averages about 0.7, indicating that roughly 50 per cent of the air temperature and rainfall oscillations are related. The phase of 180° shows that this relation is an inverse one. The physical process is one of evaporation from falling rain, which decreases the air temperature [*Riehl*, 1954].

*Coherence and phase between salinity and rain (Figure 11, right)*. As in higher latitudes [*Roden*, 1961], the coherence between these two variables depends much upon the local environment. At Hilo, on the windward side of the island of Hawaii, the average coherence between 0 and 6 cpy is about 0.6. The phase is approximately 120° instead of the expected 180°. It is not improbable that the shift in phase is due to delayed runoff through the porous volcanic rocks. A similar phase difference occurred on Guam (not shown). At Honolulu, a semienclosed harbor on the leeward side of the island of Oahu, the coherence is mostly significant at high frequencies; the phase is 180°. At Truk, a high island in the rainy intertropical convergence zone, the coherence is high at both ends of the spectru but not in between. At the remaining islands f which spectrums were computed, equally lar local differences occurred. The only more-or-l common feature was the 180° phase difference the significant part of the spectrum, whi merely indicates that rainfall and salinity a related inversely to each other.

*Conclusions*. The results of the preceding st tistical analysis can be summarized as follow

1. The rms amplitudes of the annual and n periodic oscillations are of the same order magnitude.

2. If the islands are closer to the equator th about 15°, the spectral peak corresponding the annual oscillation is not significant in s level, salinity, and rainfall records, nor in te perature and atmospheric pressure records.

3. Sea level oscillations at neighboring islan are strongly related and are in phase. The cillations at distant islands are related only low frequencies. If the islands are dominated the same wind regime, the sea level changes a in phase; if not, they sometimes are out phase.

4. Sea level and sea temperature oscillatio are directly related to each other at low fr quencies. The coherence depends upon the lo environment, being highly significant near t boundary between the equatorial upwelling a the tropical warm water regions and insignifica in semienclosed harbors.

5. No significant relation between sea le and atmospheric pressure changes is found tropical islands.

6. Sea and air temperature oscillations are d rectly related to each other at those islan where rainfall does not influence the air temper ture.

7. Sea temperature and wind speed oscil tions are inversely related at Wake Island the NE trade wind region.

8. Air temperature and rainfall oscillatio are strongly related in the zone of wet inte tropical convergence. The relation is an inver one, reflecting the effect of evaporative cooli [*Riehl*, 1954].

9. Salinity and rainfall oscillations are relat inversely to each other, but the coherence d pends much on the local environment.

10. The statistical findings are in fair agre

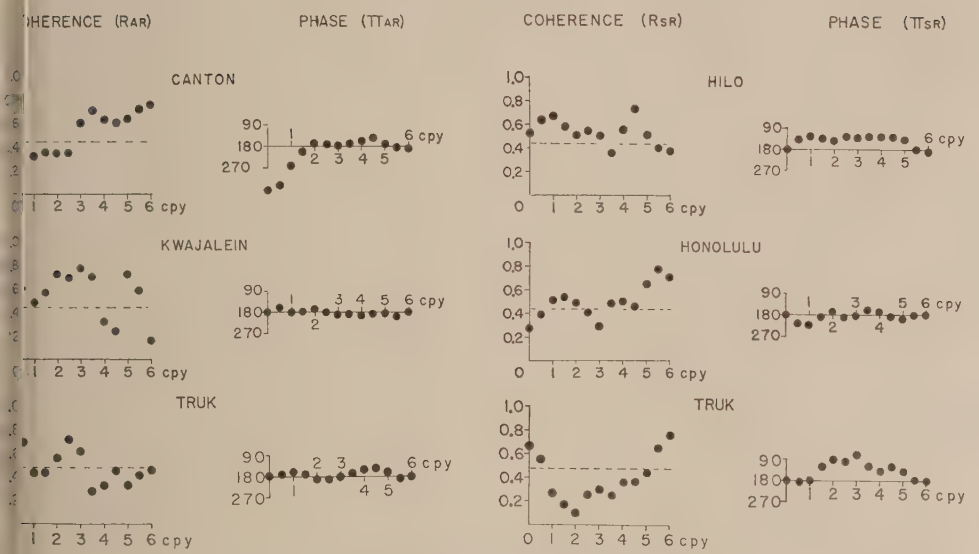



Fig. 11. *Left.* Coherence and phase between anomalies of air temperature and rain. *Right.* Coherence and phase betweeen anomalies of salinity and rain. The dashed line refers to the 95 per cent confidence limits.

t with results obtained from large-scale hy-graphic surveys.

*cknowledgments.* I am indebted to M. Black-, G. S. Cox, G. W. Groves, J. D. Isaacs, and . Reid, Jr., for discussion and advice. The rums were computed on the 1604 electronic puter of the University of California, San go. The remaining desk computations and il-rations were painstakingly done by Mrs. Terry te.

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# A Method for the Analysis of Chlorinated Benzenes in Clams (*Mercenaria mercenaria*) and Oysters (*Crassostrea virginica*)

Reprinted from the *Journal of the Association of Official Agricultural Chemists*, Vol. 46, October 1963.

# A Method for the Analysis of Chlorinated Benzenes in Clams (*Mercenaria mercenaria*) and Oysters (*Crassostrea virginica*)

By N. SCHWARTZ, H. E. GAFFNEY, M. S. SCHMUTZER, and F. D. STEFANO
(United States Testing Co., Inc., 1415 Park Avenue, Hoboken, N.J.)

**A method of analysis for mixtures of chlorinated benzenes in clam (Mercenaria mercenaria) and oyster (Crassostrea virginica) samples is reported. The method involves Soxhlet extraction with *n*-hexane-isopropanol (1:1) for 6 hours followed by gas chromatographic separation on a Silicone gum column with an electron affinity detector. Quantities as small as $10^{-10}$ g are detectable.**

**Average recovery of added Polystream (a mixture of chlorinated benzenes) was 99% for clam samples and 104% for oyster samples. Recoveries were based on reading the 1,2,3,4-tetrachlorobenzene peak. The relative precision for triplicate chromatograms, averaged over all levels, was ± 5%.**

This research was supported by the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, under Contract No. 14-17-0007-30.

The incursion of predators on clams (*Mercenaria mercenaria*) and oysters (*Crassostrea virginica*) is reported to be widespread, and threatens the existence of the clam and oyster industries. The U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, has investigated the use of chemical treatments for controlling these clam and oyster enemies.

Dr. Victor L. Loosanoff, Director of the Milford Biological Laboratory of the Bureau of Commercial Fisheries, has reported

on recent advances in the control of shellfish predators and competitors (1). The subject of chemical treatments and barriers to control shellfish predators has been discussed in detail by Loosanoff, MacKenzie, and Shearer (2–4).

Chlorinated benzenes, including orthodichlorobenzene and mixtures of chlorinated benzenes, have been found particularly effective in controlling oyster drills and other molluscan enemies. A mixture of chlorinated benzenes called Polystream has been investigated; this mixture contains about 44% 1,2,3,4-tetrachlorobenzene, 33% 1,2,4-trichlorobenzene, 9% pentachlorobenzene, and smaller amounts of isomers and other chlorinated benzenes.

After treatment of the clam and oyster beds, a method of analysis was desired to determine the amount of chlorinated benzenes present in the clams or oysters.

A method of analysis for Polystream was developed by the United States Testing Company, Inc. involving extraction, detection, and quantitative estimation of the chlorinated compounds by gas chromatography. An electron affinity detector was employed as the sensing element. The electron affinity detector used was designed and developed by the Jarrell Ash Company; this was the first commercially available electron affinity detector. This type of detector was first discovered and reported by Lovelock and Lipsky (5).

Clark applied the electron affinity detector principle to the analysis of pesticide residues in milk and a wide variety of other materials (6). More recently, Watts and Klein have reported on the analysis of chlorinated pesticide residues in vegetables, dairy products, and oils using an electron capture detector with a 56 microcurie radium source (7).

The method reported in this paper is for the detection and estimation of Polystream constituents in clam and oyster samples, including the clam and oyster fluids.

## METHOD

### *Apparatus*

(a) *Gas chromatograph.*—Beckman GC-2, equipped with an electron affinity detector manufactured by Jarrell Ash Company, was used in this work. The detector cell consists of a titanium tritide source equivalent to 100 mc tritium; this cell was maintained at the same temperature as the column (130°C for Polystream). The injection port was heated to 85°C.

(b) *Column.*—5″ stainless steel connected to the detector with Swagelok fittings.

(c) *Manometer.*—Soap bubble type, used to measure gas flow.

### *Column Substrate*

Good separations were achieved on a Silicone gum substrate (5% SE 30 on 80–100 mesh Chromosorb W). This material has a low vapor pressure under the column temperatures used and has, therefore, a satisfactory signal to noise ratio. The importance of this column criterion was stressed by Watts and Klein (7).

### *Conditions for Analysis*

The following conditions were used: column temperature, 130°C; detector temperature, 130°C; injection block temperature, 85°C; carrier gas, $N_2$ (pre-purified); $N_2$ pressure, 30 psi; $N_2$ flow rate, 227 ml/min.; standing voltage, 22 v; amplifier sensitivity, $10^{-9}$ amps; recorder sensitivity, 1 mv; chart speed, 60″/hr.

### *Procedures*

*Preparation of sample.*—To obtain a representative sample, grind the entire sample in a Waring Blendor. Place a 50 g portion of ground clam or oyster sample in a Waring Blendor. Add 100 g anhydrous $Na_2SO_4$ and mix for 1 minute.

*Soxhlet extraction with n-hexane/isopropanol (1:1).*—Transfer the macerated sample to a thimble (43 × 123 mm) containing 5 g anhydrous $Na_2SO_4$ at its bottom. Assemble the extraction apparatus with the thimble in place, and transfer any remaining material in the mixing bowl of the Waring Blendor to the thimble by washing with small volumes of *n*-hexane/isopropanol (1:1). Extract material with a total volume of 300 ml *n*-hexane for at least 6 hours. Set the heat to achieve 5–6 drainings of the thimble holder per hour.

At the end of 6 hours disconnect the thimble holder and flask from the condenser when the thimble holder is full of solvent. Drain the solvent into the flask as completely as possible through the main distillation arm of the thimble holder. Cool to room temperature, and measure the final volume of extract in a 500 ml graduated cylinder.

(The 5 g $Na_2SO_4$ at the bottom of the thim-

ole is effective in binding water and fluids that otherwise filter through the thimble. Troublesome emulsions have been observed on oyster samples due to these fluids siphoning over during the extraction.)

### *Preparation of Standard Calibration Curves*

Prepare standard solutions containing 1.00 μg/ml of the following: *o*-dichlorobenzene; 1,2,3-trichlorobenzene; 1,2,3,4-tetrachlorobenzene; and pentachlorobenzene.

Dissolve 0.1000 g of each in 1 L *n*-hexane. Pipet 10 ml into a 1 L flask, and dilute to the mark with *n*-hexane/isopropanol (1:1). This solution contains 1.00 μg chlorinated compound per ml, or 1 μl is equivalent to 1.00 nanogram.

Prepare standard calibration curves of peak height versus sample weight in μg. Inject at separate times, 1, 2, 3, 4, and 5 μl of the standard solution of chlorinated compound into the gas chromatograph (**a**). At the known retention time for the injected chlorinated compound, determine the peak height in mm. Plot a curve of peak height (amps) versus sample weight in μg.

*Chromatographic procedure.*—Inject 1–25 μl of the extract, depending upon the concentration, into the gas chromatograph. For the conditions given above, the 1,2,3,4-tetrachlorobenzene had a retention time of 378 seconds, and pentachlorobenzene had a retention time of 790 seconds. The retention time was calculated for a chart speed of 60 inches per hour, by measuring the distance from the start to the peak for the compound being measured.

Determine the peak height in mm for 1,2,3,4-tetrachlorobenzene at the above retention time. From the calibration curve for the Polystream standard, read the number of μl of the standard solution corresponding to the peak height obtained.

### *Calculations*

$$\text{Polystream, ppm} = (C \times M)/1000 \times (1000/\mu\text{l sample injected}) \times (V/\text{g sample}) = (C \times M \times V)/(\mu\text{l sample injected} \times \text{g sample})$$

where $C$ = concentration of standard solution in nanograms; $M$ = μl Polystream (based on 1,2,3,4-tetrachlorobenzene peak) read from calibration curve; $V$ = volume of final extraction in ml.

*Alternative method of calculation.*—The response of the electron affinity detector is affected by the formation of films. It was found that an injection of 10 μl benzene after each sample chromatogram was effective in clearing the detector. The following alternative procedure of reading was also helpful:

Determine the step height of the 1,2,3,4-tetrachlorobenzene peak for 10 μl of the standard solution (10.0 nanograms). Inject the sample, and determine the ratio of the step height obtained to the step height for the sample. 1 ppm Polystream in the sample is equivalent to 0.167 nanograms per μl when the final volume of extract is 300 ml. Calculate ppm Polystream as follows:

$$\text{ppm} = (\text{Step height of sample}) \; (10)/(0.167) \; (\mu\text{l sample injected}) \; (\text{step height of 10 } \mu\text{l of standard solution}).$$

This alternative method of calculation assumes linearity of response (for up to 10 μl standard solution), and zero intercept for the calibration curve. These conditions have been found to apply for the instrument used in this study. The microliters of sample injected should be such that the step height for the sample does not exceed the step height for 10 μl of the standard.

## Results and Discussion

The calibration curves for 1,2,3,4-tetrachlorobenzene and pentachlorobenzene are shown in Figs. 1 and 2. These calibration curves can be used to determine the level of chlorinated benzenes present in the blanks and in samples of clam and oyster meat containing added amounts of chlorinated benzenes.

The commercial analysis of Polystream is

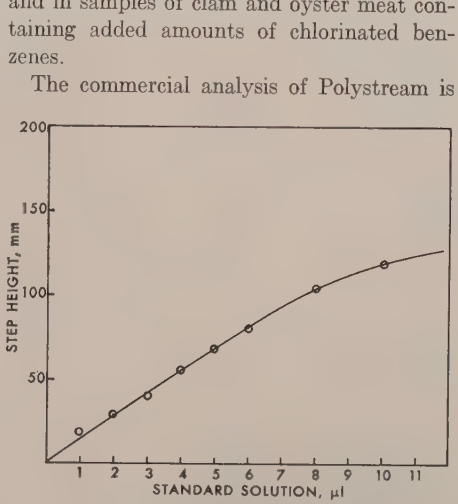


*Fig. 1*—Calibration curve for 1,2,3,4-tetrachlorobenzene. Conditions: hexane-isopropanol (1:1); 0.625 μg/ml; sensitivity, $10^{-9}$; time constant, res.; standing current, $4 \times 10^{-9}$ amps; full scale, 200 mm. Micrograms = $(M \times 0.625)/1000$. $M$ = μl standard solution.

**Table 1. Commercial analysis of Polystream**

| Constituents | % |
|---|---|
| Monochlorobenzene | 1.3 |
| *o*-Dichlorobenzene | 0.7 |
| *p*-Dichlorobenzene | 2.1 |
| 1,2,4-Trichlorobenzene | 32.9 |
| 1,2,3-Trichlorobenzene | 3.1 |
| 1,2,3,4-Tetrachlorobenzene | 44.0 |
| 1,2,4,5-Tetrachlorobenzene | 4.3 |
| Pentachlorobenzene | 9.1 |

given in Table 1. The recovery data derived from the analyses of the clam and oyster meats are summarized in Table 2. The Polystream analysis is based on the 1,2,3,4-tetrachlorobenzene peak. Average recoveries for clam and oyster extracts were 99% and 104%, respectively. The respective ranges were 93–107% and 95–130%.

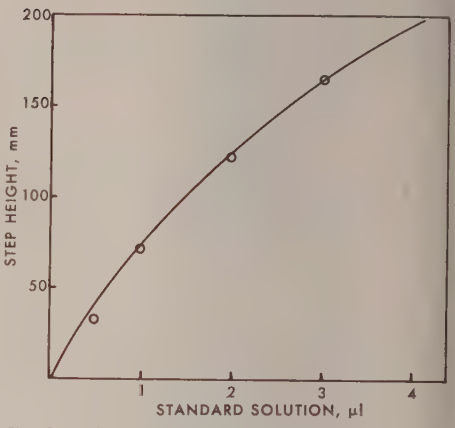


*Fig. 2*—Calibration curve for pentachlorobenzene. (Conditions same as in Fig. 1.)

There is no evidence of a specific interference on the blanks at the retention time for 1,2,3,4-tetrachlorobenzene and pentachlorobenzene; however, there is a general back-

**Table 2. Recovery of Polystream from clam and oyster samples by *n*-hexane/isopropanol extraction[a]**

| Sample No. | Polystream Added, ppm | Polystream Found, ppm | % Recovery |
|---|---|---|---|
| | | Clam Samples | |
| Jersey City Lot #1 | None | <0.10 | — |
| Jersey City Lot #2 | None | <0.10 | — |
| Control 388 | None | <0.10 | — |
| Control 429 | None | <0.10 | — |
| Control 512 | None | <0.10 | — |
| Jersey City Lot #2 | 0.10 | 0.12 | 120 |
| Jersey City Lot #2 | 0.10 | 0.10 | 100 |
| Jersey City Lot #2 | 0.10 | 0.10 | 100 |
| | | Av. 0.11 | 107 |
| Jersey City Lot #2 | 0.50 | 0.51 | 102 |
| Jersey City Lot #2 | 0.50 | 0.45 | 90 |
| Jersey City Lot #2 | 0.50 | 0.44 | 88 |
| | | Av. 0.47 | 93 |
| Jersey City Lot #2 | 1.00 | 0.92 | 92 |
| Jersey City Lot #2 | 1.00 | 0.94 | 94 |
| Jersey City Lot #2 | 1.00 | 0.94 | 94 |
| | | Av. 0.93 | 93 |

(*Continued*)

**Table 2.** (*Continued*)

| Sample No. | Polystream Added, ppm | Polystream Found, ppm | % Recovery |
|---|---|---|---|
| | | Clam Samples (*Continued*) | |
| Jersey City Lot #1 | 5.00 | 4.8 | 96 |
| Jersey City Lot #1 | 5.00 | 4.6 | 92 |
| Jersey City Lot #1 | 5.00 | 4.7 | 94 |
| | | Av. 4.7 | 94 |
| Jersey City Lot #1 | 10.0 | 9.4 | 94 |
| Jersey City Lot #1 | 10.0 | 9.8 | 98 |
| Jersey City Lot #1 | 10.0 | 10.2 | 102 |
| | | Av. 9.8 | 98 |
| | | Oyster Samples | |
| 511C | None | <0.10 | — |
| Jersey City Lot #3 | None | <0.10 | — |
| Control 386 | None | <0.10 | — |
| Control 427 | None | <0.10 | — |
| Control 515 | None | <0.10 | — |
| Jersey City Lot #3 | 0.10 | 0.14 | 140 |
| Jersey City Lot #3 | 0.10 | 0.12 | 120 |
| Jersey City Lot #3 | 0.10 | 0.13 | 130 |
| | | Av. 0.13 | 130 |
| Jersey City Lot #3 | 0.50 | 0.47 | 94 |
| Jersey City Lot #3 | 0.50 | 0.50 | 100 |
| Jersey City Lot #3 | 0.50 | 0.52 | 104 |
| | | Av. 0.50 | 100 |
| Jersey City Lot #3 | 1.00 | 0.98 | 98 |
| Jersey City Lot #3 | 1.00 | 0.90 | 90 |
| Jersey City Lot #3 | 1.00 | 1.11 | 111 |
| | | Av. 1.00 | 100 |
| 511C | 5.00 | 4.8 | 96 |
| 511C | 5.00 | 4.6 | 92 |
| 511C | 5.00 | 4.8 | 96 |
| | | Av. 4.7 | 95 |
| 511C | 10.0 | 9.2 | 92 |
| 511C | 10.0 | 9.6 | 96 |
| 511C | 10.0 | 9.7 | 97 |
| | | Av. 9.5 | 95 |

[a] Based on 1,2,3,4-tetrachlorobenzene peak.

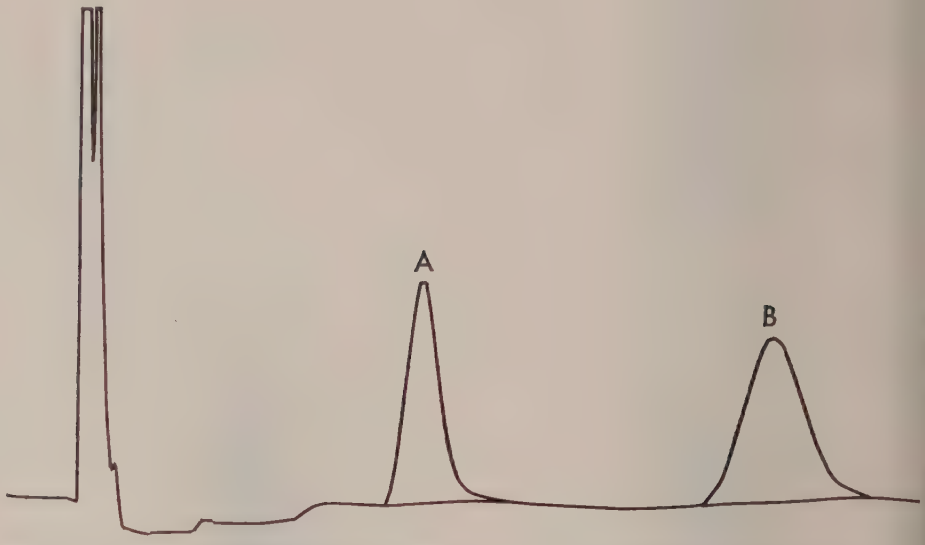


*Fig. 3*—Chromatogram of Polystream (10 μl, 0.625 μg/ml). *A*, 1,2,3,4-tetrachlorobenzene; peak height, 90 mm. *B*, pentachlorobenzene; peak height, 67 mm.

ground absorption above the baseline. For most samples analyzed, this general background does not interfere with reading the 1,2,3,4-tetrachlorobenzene and pentachlorobenzene peaks.

In proving the method, chlorinated benzenes were added to the macerated sample contained in the thimble. Extraction recoveries under these conditions do not necessarily represent conditions in exposed clams and oysters, where the chlorinated compounds may be present in the tissue. Figure 3 shows a typical chromatogram.

**Summary**

The recovery data derived from the analyses on both clam and oyster samples indicate that a 300 ml *n*-hexane/isopropanol extraction followed by injection of the extract into a gas chromatograph equipped with an electron affinity detector is a concise, sensitive method of analysis for the chlorinated benzenes. This procedure eliminates transfer to a chromatographic column for cleanup (reduced opportunity of sample loss) and extraneous impurity peaks in the chromatograms. It is a fast, accurate, and relatively simple method of analyzing for Polystream in clam and oyster samples.

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# Infection of *Crassostrea virginica* (Gmelin) from Hawaii with a Larval Tapeworm, *Tylocephalum*

ALBERT K. SPARKS[1,2]

*College of Fisheries, University of Washington, Seattle, Washington*

*Accepted December 29, 1962*

During a survey of the oyster potential of Hawaii, all oysters [*Crassostrea virginica* (Gmelin)] examined were found to be infected in the region of the digestive diverticula with numerous, small, fibrous cysts containing larval cestodes of the genus *Tylocephalum*. This genus is common in the digestive gland of bivalve molluscs in the Orient, having once been thought to be the cause of natural pearl formation in pearl oysters, but has not been previously reported in *Crassostrea virginica*.

## Introduction

During a survey of the oyster potential of Hawaii (Sparks, 1962) a number of eastern oysters [*Crassostrea virginica* (Gmelin)] from West Loch, Pearl Harbor, were fixed, sectioned, stained, and examined for the presence of pathogenic microorganisms. All specimens examined were infected with large numbers of small encysted helminths, enclosed in a thick fibrous cyst (Fig. 1). It was not possible in the sectioned material to ascertain the identity of the worms other than that they belonged to the phylum Platyhelminthes. Subsequently, a shipment of live oysters was obtained and examined fresh. Again, all specimens examined were found to harbor large numbers of the helminth which were, while alive, readily identified as larval cestodes belonging to the genus *Tylocephalum*.

This genus was placed in the order Lecanicephaloidea and in the family Cephalobothridae by Southwell (1930) and possesses a characteristic scolex with a protrusible glandular mass in the anterior portion (see Figs. 2 and 3). These forms are reported to be extremely common in the

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region of the digestive gland of pearl oysters and other bivalves in the Orient, but have not, to the author's knowledge, been listed in edible oysters, and certainly not in *Crassostrea virginica*. These forms were thought by several investigators to be the cause of natural pearl formation

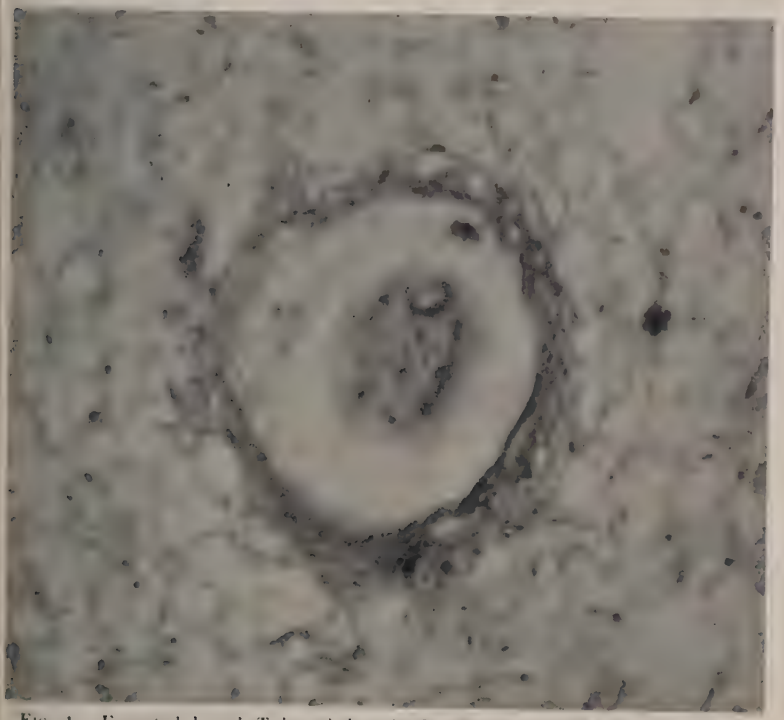

FIG. 1. Encysted larval *Tylocephalum* in Leydig tissue of *Crassostrea virginica*. H&E stain of fixed preparation. 500 ×.

in pearl oysters (Herdman and Hornell, 1906; and Southwell, 1924), but as pointed out by Hyman (1951) in her summary of the group, Jameson (1912) exploded this theory of pearl formation.

## Materials and Methods

The original material was fixed in Zenker's fluid, sectioned at 5 microns and stained with Harris' hematoxylin and eosin. Subsequent material was examined fresh by teasing the cysts from live oysters with the aid of a steroscopic microscope, and was studied with a compound microscope.

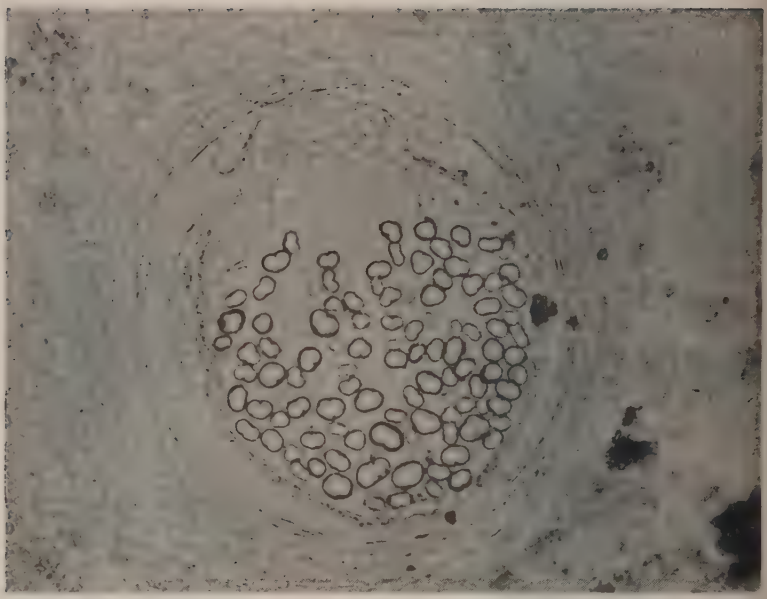

FIG. 2. Fresh preparation of cyst of *Tylocephalum* larvae from digestive tubule area of *C. virginica*. 800 ×.

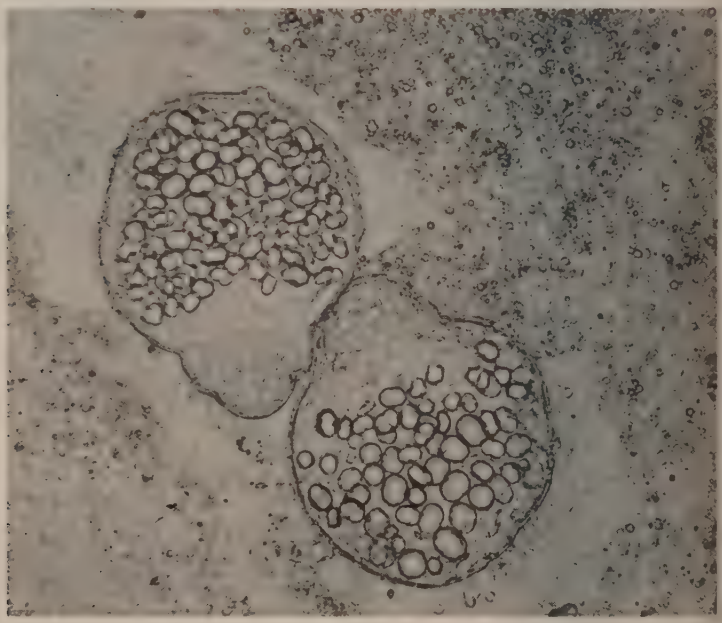

FIG. 3. Larval *Tylocephalum* teased from cysts, living material. 800 ×.

## Results

All oysters examined possessed, in the region of the digestive diverticula, numerous small (100μ × 120μ capsule diameter) larval tapeworms enclosed in a thick fibrous cyst (Figs. 1 and 2). Whether the cyst wall is produced by the helminth or the oyster is not known, but it is assumed that the extensive cysts are the result of a fibrosis of the host tissue in response to the invasion of the parasite. Occasionally the cysts are found in the walls of the gut or the digestive tubules, but the typical location is the loose connective tissue between the digestive diverticula and beneath the gut.

When the larval worms are disturbed (Fig. 2) or teased from the cyst (Fig. 3), the globular scolex is everted and the worms actively move about.

## Discussion and Conclusions

Since the members of the order Lecanicephaloidea are, so far as is known, inhabitants of the gut or spiral valve of elasmobranchs as adults, there appears to be little likelihood of larval forms of this cestode being a matter of concern from a public health point of view. Biologically, it is of interest that the eastern oyster, an introduced species in Hawaii, is utilized as a host by *Tylocephalum*. Whether a pathogenic effect on the oyster results from infection is not known, with no histopathological indications noted other than the extensive cyst formation, but the Condition Indices of oysters from numerous locations in Pearl Harbor were consistently much lower than normal for the species for the season of the year. The lowered Condition Index, a measure of fatness or marketability, demonstrates that some factor caused the condition of the oysters in Pearl Harbor to be lowered. There appears to be sufficient food in the area, as indicated by extremely high coliform bacteria counts in the water, but the oysters are growing under crowded conditions. It is not known whether the lowered Condition Index has resulted from the crowding or, possibly, from the heavy infections of the cestode.

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After the present report had gone to press, Richard W. Burton of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland determined by histological examination that a group of oysters transplanted from Apalachicola Bay, Florida to Chincoteague Bay, Maryland were infected with the same tapeworm, or with a closely related form. This finding was reported at the 5th Annual Shellfish Mortality

Workshop held at the Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland, January 29–30, 1963.

Acknowledgments

The sectioned material for this study was prepared by Mr. Gilbert Pauley and the photomicrographs were prepared by Mr. Raymond Simon, both of the College of Fisheries. The original material was collected by the author and the subsequent material was collected and shipped by personnel of the Hawaiian Division of Fish and Game.

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# PHYSIOLOGICAL FACTORS AFFECTING THE INTERPRETATION OF PHYTOPLANKTON PRODUCTION MEASUREMENTS

WILLIAM H. THOMAS
University of California
Scripps Institution of Oceanography
La Jolla, California

## ABSTRACT

Although other methods have been used to measure phytoplankton production, this paper discusses only the physiological factors which affect the interpretation of carbon-14 measurements of production. In principle, gross or "real" photosynthesis will be measured by the carbon-14 method if the following conditions are met: (1) carbon-14 is assimilated at the same rate as carbon-12; (2) no carbon-14 is incorporated by processes other than photosynthesis; (3) no assimilated carbon-14 is lost by excretion; and (4) no carbon-14 is lost by respiration which accompanies photosynthesis. In practice, none of these conditions is completely satisfied, but the data may be corrected for deviations from these conditions.

The correction for the difference in the rate of assimilation of the two isotopes (1, above) has been ascertained at plus 6 per cent. The correction for non-photosynthetic uptake of carbon-14 (2, above) may be made by incubating a darkened aliquot simultaneously with an illuminated one. Further studies are needed on the excretion (3, above) of organic matter by marine phytoplankton. This correction is probably small, but may depend upon incubation and nutrient conditions.

To correct for respiration (4, above), the ratio of photosynthesis to respiration (P/R) and the amount of intermixing between the two processes must be known. If 100 per cent of the respiratory $CO_2$ is preferentially reutilized in photosynthesis, and no respiratory correction is made, the carbon-14 method will measure net photosynthesis. Early tests of this concept measured photoinhibition of the respiratory release of $C^{14}O_2$ from labeled cells. Comparisons were also made between carbon-14 uptake (uncorrected for respiration) and net $O_2$ evolution under various illumination and nutrient conditions. More recently, carbon-14 uptake has been compared with growth.

Under conditions of saturating light intensities and adequate intracellular nutrient levels, net $O_2$ evolution differs very little from gross $O_2$ evolution (the respiration correction is small) and carbon-14 uptake agrees with both measurements within experimental error. In cultures maintained under such conditions, logarithmic growth constants, calculated from increases in cell concentration or other growth measurements, are statistically equivalent to similar constants calculated from carbon-14 uptake or net $O_2$ evolution rates and organic carbon analyses.

At subsaturating light intensities, carbon-14 uptake is equivalent to or is less than net $O_2$ evolution, and this relationship obtains down to the compensation intensity for $O_2$ evolution. At or below the compensation intensity, carbon-14 uptake more closely approximates gross $O_2$ production, but the values are very uncertain.

In incipiently nutrient-deficient algal cultures, net $O_2$ evolution also does not differ significantly from gross $O_2$ evolution; carbon-14 assimilation (uncorrected for respiration) is equivalent to either net or gross $O_2$ production. Growth constants decrease as deficiency progresses, but constants calculated from either $O_2$ evolution or carbon-14 uptake are equivalent to those calculated from growth measurements.

In extremely deficient cultures (at P/R ratios down to 2), carbon-14 uptake (uncorrected for respiration) agrees with net $O_2$ evolution and differs greatly from gross $O_2$ evolution. As deficiency progresses, the P/R ratio decreases even more, and gross $O_2$ evolution may become less than respiration. Comparisons of carbon-14 uptake and $O_2$ evolution are inconclusive under such extreme conditions. Such conditions have little oceanographic significance, since a natural population could not persist at P/R ratios less than 2.

These results are discussed in relation to nutrient and illumination conditions which might be present in the sea. Under most conditions, the carbon-14 method (uncorrected for respiration) appears to measure a net process, such as algal growth or net $O_2$ evolution.

## INTRODUCTION

Several different methods have been developed for the measurement of phytoplankton production in the sea. Because of its great sensitivity, the carbon-14 method of Steemann-Nielsen (1952) has come into the widest use, and most marine biological laboratories are now making intensive studies of carbon-14 uptake by phytoplankton in their regions of interest. All methods of measuring phytoplankton production and various other aspects of algal growth and physiology were comprehensively discussed in an excellent review by Strickland (1960). The reader is referred to that paper for more detailed treatment than can be given here.

When the carbon-14 method was first used during the cruise of the Galathea around the world, the values for one area—the Sargasso Sea—were 10-200 times less than previous values obtained with the oxygen method by Riley, et al. (1949). This discrepancy led to a great deal of controversy regarding just what was measured by the carbon-14 method. Workers at Woods Hole (Ryther, 1954b and 1956b) claimed that the method measured net production, while Steemann-Nielsen maintained that the data, when certain corrections were introduced, are equivalent to gross production. One of the purposes of the present paper is to examine and review these corrections, and the physiological factors affecting them.

This controversy has led workers in some laboratories to wonder whether the carbon-14 method was an adequate measure of an increase in algal biomass. Another purpose of this paper is to summarize recent results comparing carbon-14 uptake with growth in algal cultures.

In principle, gross or total photosynthesis will be measured by the carbon-14 method if the following conditions are met: (1) carbon-14 is assimilated at the same rate as the stable isotope of carbon, carbon-12; (2) no carbon-14 is incorporated by the processes other than photosynthesis; (3) no assimilated carbon-14 is lost by excretion or autolysis during the incubation, or by rupture of cells during filtration; and (4) no assimilated carbon-14 is lost by the intermixing of respiration with photosynthesis. However, in practice, none of these conditions is completely satisfied, and if gross photosynthesis is to be calculated, the raw data must be corrected for deviations from them.

## CORRECTIONS FOR CARBON-FOURTEEN DATA

### The Isotope Effect

Theoretically, because $C^{14}O_2$ has a molecular weight which is 4.5% heavier than that of $C^{12}O_2$, assimilation of $C^{14}O_2$ should proceed at a proportionally slower rate than that of $C^{12}O_2$. Early estimates of this isotope effect in photosynthesis indicated that $C^{14}O_2$ was assimilated approximately 15% more slowly than $C^{12}O_2$ (Weigle, Warrington, and Calvin, 1951; Van Norman and Brown, 1952). In these experiments the concentration of these isotopes was recorded automatically during periods of photosynthesis lasting about 30 minutes. After 30 minutes, the concentration of $CO_2$ had decreased to nearly zero and photosynthesis had nearly ceased. The

isotope effect was measured during the period when photosynthesis proceeded at a constant and high rate. These studies, while technically very elegant, did not yield unequivocal determinations of the magnitude of the isotope effect. Experimental errors were large and the corrections applied to the data for dark uptake (exchange) and respiration were also large (cf. Craig, 1954; Steemann-Nielsen, 1955b). Furthermore, the half-hour period is much shorter than that used in routine productivity measurements.

In his original paper Steemann-Nielsen (1952) used a value of 6% to correct for the isotope effect. He also recalculated Van Norman and Brown's results and found a value of 5% (Steemann-Nielsen, 1955b).

More recently, Buchanan et al. (1953) and Sorokin (1960) compared specific activities (cpm/carbon concentration) in Scenedesmus cells with specific activities of the medium following several weeks of growth in labeled medium. In both studies the specific activity of the algae was 6.5% less than that of the medium, and the experimental error was much less than in previous determinations.

These two types of experiments may give different results because the experimental times were greatly different. Short-time experiments refer to photosynthesis whereas long-term experiments may include isotope fractionation in all of the many biochemical reactions in which carbon participates. The isotope effect could be determined using incubation periods comparable to those normally used in productivity studies by comparing pH changes in dense cultures with carbon-14 uptake. This was attempted by Thomas (unpublished data), but experimental errors were too large. If these errors are ignored, the effect is about 9% during a 4-hour photosynthetic period, a value which is intermediate between short-term results and those obtained during long-term algal growth. More effort is needed to reduce the error in such comparisons, and the use of high-precision pH meters and more precise counting methods than Geiger counting may provide unequivocal values for the isotope effect. Until more precise measurements are made, which are also comparable to the usual productivity measurement, a factor of 5% appears reasonable to use in routine surveys of phytoplankton production.

### Non-Photosynthetic Assimilation of Carbon-14

During incubation of algae with carbon-14, a certain amount of the tracer will be taken up by processes other than photosynthesis. In his original description of the method, Steemann-Nielsen (1952) subtracted one percent from the radioactivity taken up by light-saturated phytoplankton to correct for non-photosynthetic assimilation. In healthy algal cultures, fixation of carbon-14 in the dark is similar to the one percent value applied by Steemann-Nielsen (Brown et al., 1949; Thomas, unpublished). However, under conditions of extreme nitrogen deficiency, assimilation in darkened cultures may reach 37% of that in illuminated cultures (Steemann-Nielsen and Al Kholy, 1956). A similar high value for dark fixation was not found for phosphate-deficient cultures. If such an increase in relative dark uptake were characteristic of nitrogen-deficient algae in general, measurements of dark uptake might be a useful index of the nitrogen status of natural populations. This hypothesis needs to be substantiated. Perhaps the nitrogen/carbon ratio or carotenoid/chlorophyll ratio of cultures or natural populations can be correlated with relative dark uptake.

In natural populations, dark fixation can be greater than a few percent of the value for photosynthetic fixation of carbon-14 (Doty, 1958a; Holmes, 1958b; Thomas and Simmons, 1960). Detailed recent measurements by Steemann-Nielsen (1960a) of assimilation in darkened bottles showed that it could be as high as 9% of assimilation in the light for surface samples and up to 30% for samples from deep water. However, most of the values were 1 to 3%.

In view of these variations and the possible effects of varying intracellular nutritional status, it seems unwise to apply a standard correction for dark uptake uniformly to all samples during routine productivity surveys. Wherever possible, darkened bottles should be incubated with illuminated ones to establish an empirical correction.

### Losses of Labeled Carbon by Excretion or Rupture of Cells During Filtration

As $C^{14}O_2$ is taken up during incubation and converted into labeled organic matter, some of it may be excreted and go into solution outside the cell. Similarly, if a cell containing labeled

organic matter were to die and rupture during incubation or filtration, part of the radioactivity would be lost. The carbon-14 method underestimates total photosynthesis to the extent that excretion or rupture occurs. Most investigators of marine productivity have neglected such losses since early studies of algal excretion indicated that about 95% of the carbon in healthy cultures was contained within the cells (Myers and Johnson, 1949, and others). However, more recent investigations have indicated that appreciable amounts of carbon can be excreted from algal cells (Allen, 1956; Guillard and Wangersky, 1958).

Using carbon-14, Fogg (1958) measured excretion and photosynthesis by natural populations in two Swedish lakes. After incubation with carbon-14 in situ and filtration, he removed the excess radioactive carbon dioxide from the filtrate by acidification and aeration, and evaporated the filtrate to dryness. The residue was extracted with ethanol and the extract tested for radioactivity. In all samples, some radioactivity was found in the extract. Fogg expressed this activity as a fraction of that retained by the filter. In surface samples from the eutrophic Lake Erken, the excreted activity was only 2% of that retained by the filter. At 10 meters it had increased to 8%, and was 21% in a dark bottle control from 10 meters. The relative excreted activity in samples from the oligotrophic Torneträsk was somewhat greater than in samples from Lake Erken. The samples from Torneträsk were incubated for 40 hours in rainy weather; those from Erken were incubated for 24 hours in overcast weather.

These results show that excretion may be affected by light intensity, since excretion increased with increasing depth. Excretion was also greater in an oligotrophic lake as compared with a eutrophic lake, a result which might be attributed to nutrient deficiency, although illumination conditions were also different. With regard to the effects of deficiency it might be mentioned that Guillard and Wangersky (1958) found maximum quantities of extra-cellular carbohydrates in senescent cultures of marine flagellates. Such cultures presumably could have been nutrient-limited. Similarly, excreted radioactivity (that which passed a PH Millipore filter) was found in old cultures of carbon-14-labelled Dunaliella primolecta, but not in young cultures (Lasker and Holmes, 1957).

Lasker and Holmes also investigated the relative retention of radioactivity from labelled Dunaliella cultures by different filters. AA Millipore filters (pore size 0.8 $\mu$) generally retained less radioactivity than HA filters (pore size 0.5 $\mu$) or PH filters (pore size 0.30 $\mu$). With Dunaliella, HA and PH filters retained equivalent amounts of activity. Holmes and Anderson (cf. Holmes, 1961b) have continued to investigate retention by different filters, using labeled natural populations from the Friday Harbor vicinity. Many successive experiments in July and August 1960 showed that generally the PH filter retained more activity than the HA filter. The average increase in retention was 30%, but this increase varied considerably from experiment to experiment. In five experiments where the GS filter (pore size 0.22 $\mu$) was compared with the PH filter, the GS retained more activity than the PH. However, during a recent Scripps cruise to tropical waters, the GS did not always retain more activity than the PH (Holmes, personal communication). Since the porosities of the PH and GS filters are less than the sizes of all known photosynthetic organisms, it appears that the cells are rupturing during filtration and fragments are retained by the filters. This view is supported by recent experiments with natural populations off the Oregon coast which showed that, for a filter of a given porosity, retention was inversely related to the amount of vacuum used in filtration (Anderson and Holmes, personal communication).

More knowledge is now needed of just how fine a filter is necessary to retain all or most of the radioactivity from carbon-14-labelled natural populations, and also what negative pressure should be used for filtrations. We need to know whether the PH filter (now used routinely at Scripps Institution of Oceanography and the University of Washington) is capable to retaining a constant proportion of the total radioactivity. The approaches of Fogg and of Holmes and Anderson could profitably be combined in a single investigation comparing retention by various filters with the amount of activity passed by each filter. Further definition of the effects of light intensity or intracellular nutrient status on excretion is also needed. The results of Fogg and Guillard and Wangersky provide preliminary evidence that such factors will affect excretion.

## Respiratory Losses of Labelled Carbon

The application of a correction for respiration that accompanies photosynthesis remains somewhat uncertain. This correction is dependent upon the rate of respiration relative to that of gross or total photosynthesis. For healthy algal cells incubated at high light intensities, respiration is about 10% of photosynthesis. As the intensity decreases below saturation, the ratio of photosynthesis to respiration also decreases. The P/R ratio also decreases as cells become nutrient-deficient (Ryther, 1954b; Thomas, unpublished). In natural marine populations, respiration was 15% (or less) of the light-saturated rate of photosynthesis in 90% of some 78 determinations made by Steemann-Nielsen and Hansen (1959a), off Greenland. It is probable that in nature, respiration rarely exceeds 50% of photosynthesis, since, assuming 12 hours of daylight, photosynthesis must be twice respiration to balance the loss of carbon from the algae during the night. Otherwise the phytoplankton population would not persist (Steemann-Nielsen and Al Kholy, 1956; Strickland, 1960).

The other factor which enters into the application of a correction for respiration is the extent of intermixing of respiration with photosynthesis. This subject was reviewed by Rabinowitch (1956), but the magnitude of intermixing and its mechanism remain somewhat obscure. The nature of the mechanism of intermixing (be it inhibition of respiration, respiration of previously labeled organic matter, a preferential reutilization of respired $CO_2$, etc.) is of interest to the physiologist; the ecologist who applies the carbon-14 method needs only to know the magnitude of the correction, if any, that he should apply to raw carbon-14 data to determine total photosynthesis, but even this is uncertain and variable.

The first workers to apply isotopic tracers to this problem, Weigle, Warrington, and Calvin (1951), measured changes in total $CO_2$ and radioactive $CO_2$ during the incubation of barley leaves for alternating dark and light periods. From these changes they calculated changes in specific radioactivity which could only be explained by postulating that respiration in the light was only 50% of that in darkness. Using a recording mass spectrometer to measure changes in oxygen isotopes in a Chlorella suspension during alternate light and dark periods, Brown (1953) generally found no change in oxygen uptake due to light. Results with the blue-green alga, Anabaena, were less conclusive, and ranged from nearly complete inhibition at low oxygen tensions to a two and one-half fold stimulation at high light intensities and high oxygen tensions (Brown and Webster, 1953).

It may be argued that measurements of changes in oxygen uptake have little to do with the possible losses of tracer carbon during a productivity measurement. Thus, the data of Steemann-Nielsen (1955b) and of Ryther (1956c), are perhaps more applicable. The loss of carbon-14 from previously labeled algae was measured in the light and in darkness. Steemann-Nielsen labeled Chlorella for one and one-half hours, and transferred the cells to non-radioactive medium. During incubation periods of up to a further seven hours, he found that the amount of tracer released in the light was only 30-40% of that released in darkness. Ryther grew Dunaliella cells for several days in a medium containing carbon-14. He then transferred the cells to a non-radioactive medium and incubated them in the light and in darkness for 24 hours. Illumination completely suppressed the release of carbon-14 from the cells. More recent studies with a recording mass spectrometer and carbon isotopes tend to support the contention of Steemann-Nielsen that release of $CO_2$ is not completely inhibited by light. Brown and Weis (1959) showed that the production of $CO_2$ by Ankistrodesmus was inhibited about 50% by light, and that this inhibition was independent of light intensity. Similar results were obtained using Ochromonas cultures. (Weis and Brown, 1959).

If no $C^{14}O_2$ is released to the external medium at all, one can assume that respiratory $C^{14}O_2$ is being taken up preferentially within the cell, and reutilized in photosynthesis. Thus less carbon-14 will be taken up from the external medium and the method will measure net photosynthesis. If only part of the respiratory $C^{14}O_2$ is reutilized then the carbon-14 measurement will be equivalent to some value between net and gross photosynthesis. The crucial aspect of the correction for respiration is the P/R ratio, and the amount of intermixing of the two processes is of less importance. In Table 1, two sets of correction factors for respiration, by which raw carbon-14 data may be multiplied to obtain gross photosynthesis, are calculated. One set of factors is calculated assuming complete photoinhibition of respiratory

Table 1— Factors to Correct Carbon-14 Data for Respiration in Order to Obtain a Value for Gross Photosynthesis

| P/R Ratio | Calculated according to Ryther (100% photoinhibition) | Calculated according to Steemann-Nielsen (60% photoinhibition) |
|---|---|---|
| 20 | 1.05 | 1.03 |
| 10 | 1.10 | 1.06 |
| 5 | 1.20 | 1.12 |
| 3 | 1.33 | 1.20 |
| 2 | 1.50 | 1.30 |
| 1.5 | 1.67 | 1.40 |
| 1 | 2.00 | 1.60 |

$C^{14}O_2$ release (Ryther, 1956c); the other set is calculated assuming 60% photoinhibition (Steemann-Nielsen, 1955b). Note that the difference between the two factors is excessive only at P/R ratios of less than 2.

## GENERAL REMARKS ON THE COMPARISONS OF THE CARBON-14 METHOD WITH $O_2$ EVOLUTION AND WITH GROWTH

In the above discussion of corrections that may be applied to raw carbon-14 data, most of the evidence was direct; changes in the carbon-14 content of algal cells or in the rate of uptake of carbon-14 were described. The method has also been compared with other methods of measuring the rate of increase of cell material, i.e., with the $O_2$ method of measuring photosynthesis and with various measurements of algal growth. Any such comparison is less direct and is dependent upon an assessment of the over-all error of each method.

The carbon-14 method, in our laboratory, has an over-all precision of approximately ±15%. The standard error (sampling and counting error) of the uptake of radioactivity by 10 replicate cultures incubated under identical conditions was ±7%; the error in determining the amount of radioactivity added (by extrapolating our self-absorption curve to zero) was ±4%; and the error in measuring the total $CO_2$ content of the suspending medium was ±6%. Pooling these three sources of error gives an over-all value of ±15%. In the field, the sampling error will generally be greater than ±7% (cf. Holmes, Schaefer, and Shimade, 1958; Cassie, this volume). The use of very precise methods of measuring radioactivity and $CO_2$ content would probably reduce the over-all error, even in the laboratory, by only one-half, and the additional time and expense seem hardly worth the effort, except for possibly making more precise estimates of the isotope effect.

In our hands, the precision of measurements of net and gross $O_2$ evolution is about ±4%, providing the results are only expressed in ml. $O_2$/liter/hours. However, for comparison with carbon-14 uptake, the $O_2$ values must be converted to equivalent carbon production. For this conversion, a photosynthetic quotient must be selected that may vary as much as ±12% depending on nutritional or illumination conditions (Ryther, 1956b). Thus, the over-all error is nearly as much—±13%—as that of the carbon-14 method.

Growth in an algal culture—and sometimes in nature (Verduin, 1952b)—proceeds in a logarithmic fashion until such time as the culture becomes so dense that nutrients are depleted or illumination within the culture is reduced by mutual shading. Logarithmic growth can be expressed by the following equation:

$$K_2 = \frac{\log_2 C_2 - \log_2 C_1}{t_2 - t_1}$$

where $C_2$ and $C_1$ are concentrations of cell material at times $t_2$ and $t_1$. $K_2$ is the reciprocal of the time taken for the population to double, providing logarithms to the base 2 are used ($\log_2 = 3.32 \times \log_{10}$). This time can be called the generation time. $C_2$ and $C_1$ can be measured to various ways: cell concentration, optical density, cell carbon or nitrogen, dry weight, etc.

To compare photosynthesis with growth, it is necessary that $C_1$ be measured before the photosynthetic period and expressed in the same units as photosynthesis. Then a photosynthetic $K_2$ value can be calculated and compared with the $K_2$ determined from growth measurements. Suppose that a culture containing 32 mg. organic carbon per liter is photosynthesizing at a rate of 1 mg C/liter/hour. The calculation of a photosynthetic $K_2$ value is shown in Table 2. $K_2$ values calculated from growth or photosynthesis measurements are subject to the experimental error of both $C_1$ and $C_2$, and are therefore somewhat less precise than either $C_1$, or $C_2$ or the rate of photosynthesis. The comparison of growth with photosynthesis is thus made on a statistical basis.

Table 2—Sample Calculation of a Photosynthetic $K_2$ Value

$C_1 = 32$ mg. C/L  Photosynthesis = 1 mg. C/L/hour

$C_2 = 32 + 1 = 33$ mg. C/L

$t_1 = 0$

$t_2 = 1$

$$K_2 = \frac{3.32 \log_{10} 33 - 3.32 \log_{10} 32}{1} = \frac{3.32\ (1.51851 - 1.50515)}{1}$$

$$= 0.0444 \text{ hours}^{-1}$$

Generation time = $1/0.0444 = 22.5$ hours

## THE EFFECT OF LIGHT

### Corrections and Comparisons at Saturating Light Intensities

Assuming that saturation of photosynthesis occurs at an illuminance of 2000 foot-candles (cf. Ryther, 1956a), saturating intensities will occur at an optical depth of 20% at noon on a bright day and near the surface of a dull day. The saturation intensity will vary with the species composition of the phytoplankton population (Ryther, 1956a) and with its previous history of illumination (Ryther and Menzel, 1959; Steemann-Nielsen and Hansen, 1959b). Ideally, to estimate illumination conditions during a carbon-14 measurement, each investigator should make his own light saturation and species composition studies of the population(s) with which he is dealing. Then he can make a more precise estimate of corrections to apply to obtain gross photosynthesis values.

At saturating intensities, the P/R ratio will be 10-20, and these corrections will be relatively small, +5% for the isotope effect, –1% for dark uptake (assuming no dark bottle), +3% for excretion (assuming no rupture of cells on the filter pad), and +5-10% for respiration. The overall correction will be about +15% and is roughly equivalent to the experimental error of the carbon-14 method.

Since the P/R ratio is relatively great, gross photosynthesis will not differ greatly from net photosynthesis, and under such conditions carbon-14 uptake does not differ significantly from either net or gross $O_2$ evolution. Good agreement between gross $O_2$ production and carbon-14 uptake at 1000 foot-candles was first demonstrated by Ryther and Vaccaro (1954) using both Nitzschia cultures and natural populations in coastal sea water. Equivalence between net $O_2$ evolution and carbon-14 uptake at saturation was later shown by Ryther (1956b), and this is shown in Figure 1. In this experiment, gross $O_2$ production differed so greatly from net production (the P/R ratio was about 2) that one suspects that the culture was nutrient deficient. More realistic comparisons ($P/R \cong 5$) were made by Ichimura and Saijo (1958) and are reproduced in Figures 2 and 3. Considering the uncertainties in the photosynthetic quotient (these authors used 1.0) and in dark uptake, the carbon-14 results appear to agree with both

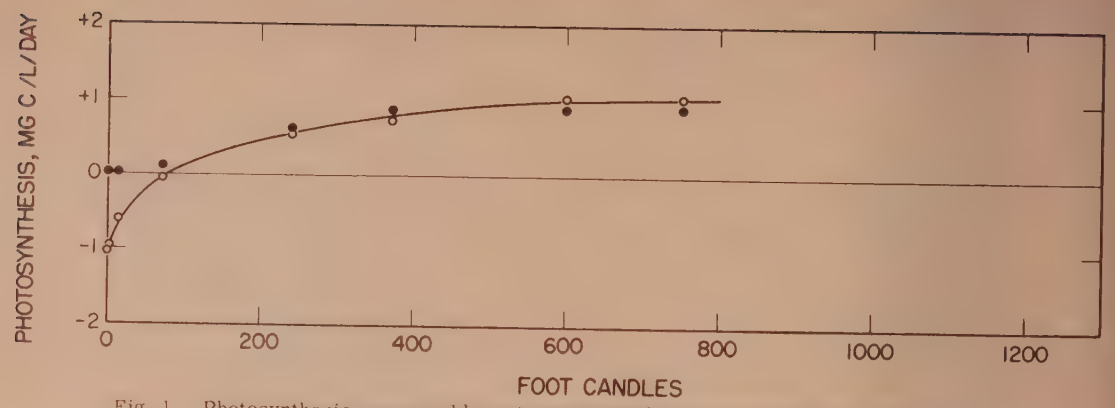


Fig. 1 — Photosynthesis measured by net oxygen production (open circles) and carbon-14 uptake (filled circles) as a function of light intensity in a pure culture of Dunaliella euchlora. (Reproduced from Ryther, 1956).

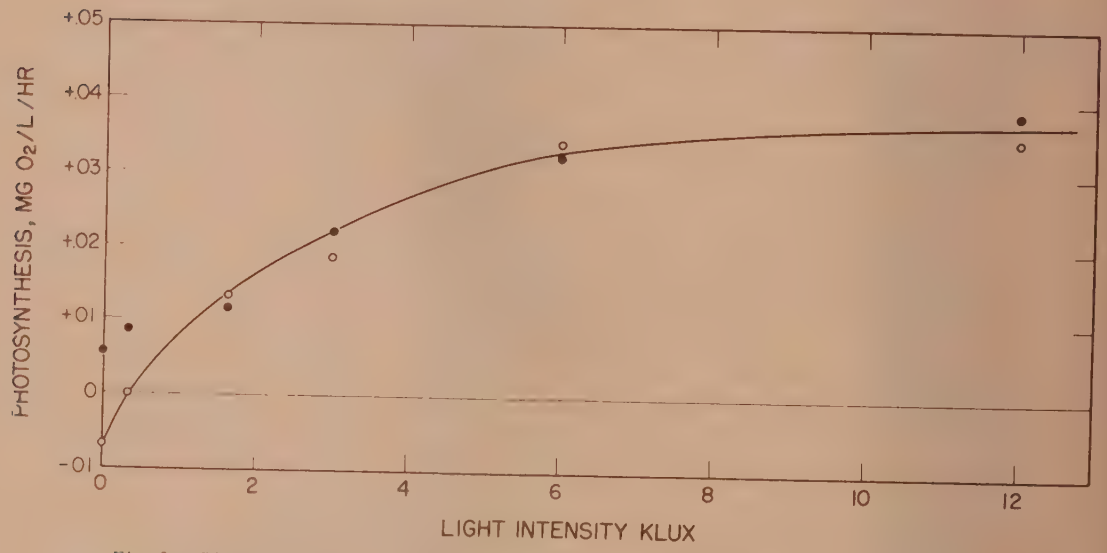


Fig. 2 — Photosynthesis measured by oxygen production (open circles) and carbon-14 uptake (filled circles) in a pure culture of Chlorella sp. (Reproduced from Ichimura and Saijo, 1958).

net or gross $O_2$ evolution at saturating illuminances, although most carbon-14 values were closer to net $O_2$ production.

In our laboratory, we have been using cultures of Dunaliella primolecta for extensive comparisons of carbon-14 uptake with $O_2$ evolution and growth. (Thomas, unpublished). In 35 comparisons of carbon-14 uptake and $O_2$ evolution at saturating light intensities, carbon-14 uptake was 101 ±23% of net $O_2$ evolution and 83 ±19% of gross $O_2$ evolution. These carbon-14 data were corrected for isotope effect and dark uptake, but not for respiration or excretion. In 20 determinations where photosynthetic capacity (photosynthesis/cell) was determined, no significant differences were found between capacities determined from carbon-14 uptake, net $O_2$ evolution, or gross $O_2$ evolution.

To compare growth with photosynthesis, we grew Dunaliella in a 40-liter aquarium which was illuminated from below with a bank of fluorescent lights. Samples were taken from the culture at various intervals for measurements of cell material and aliquots of each sample were also dispensed into glass-stoppered bottles for photosynthesis measurements. The bottles were placed on the bottom of the culture itself in an attempt to ensure that conditions were the same for photosynthesis as for growth.

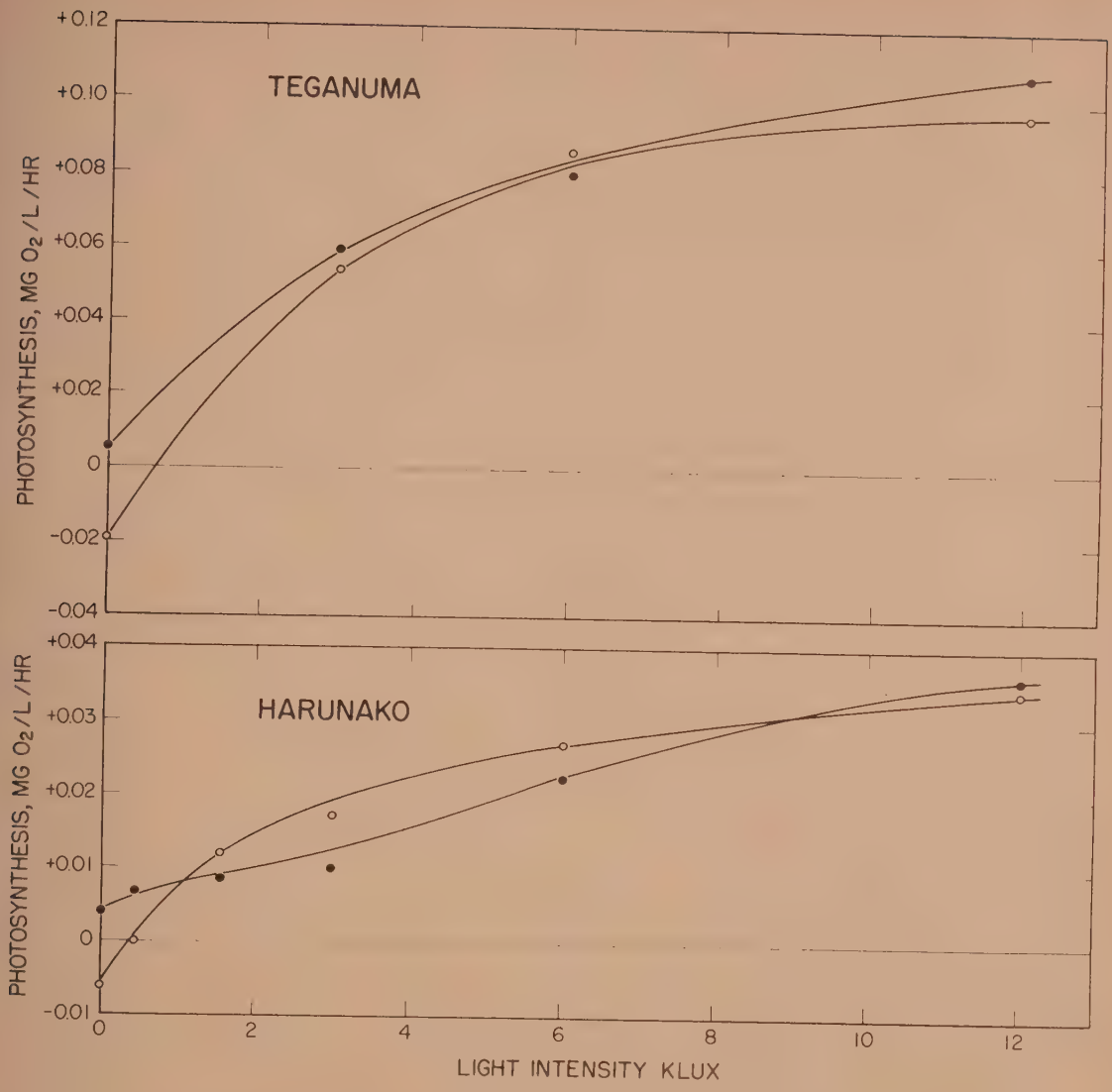


Fig. 3—Photosynthesis measured by $O_2$ (open circles) and carbon-14 (filled circles) methods in water samples taken from the eutrophic Lake Teganuma and the mesotrophic Lake Harunako. (Reproduced from Ichimura and Saijo, 1958).

When we first made this comparison, we found that the $K_2$ values calculated for growth in the whole culture were 30-40% less than those calculated for photosynthetic bottles placed in the bottom of the culture. This is shown in Figure 4. The difference between $K_2$ values for growth and photosynthesis was statistically significant ($p < 0.01$) and was attributed to a difference in illumination between the bottles and the culture as a whole. When this experiment was repeated with a culture that was less dense, the mean $K_2$ value for photosynthesis was 0.0945 hours$^{-1}$, while that for growth was 0.0835 hours$^{-1}$. This difference was not significant and photosynthesis as measured by net $O_2$ production and carbon-14 uptake was equivalent to growth. Rough calculations indicated that illuminances in bottles and in the culture did not differ more than about 10%.

### Carbon-14 Measurements at Subsaturating Light Intensities

As light intensities decrease below saturation, the various corrections increase and the validity of the carbon-14 method becomes less certain. The correction for the isotope effect

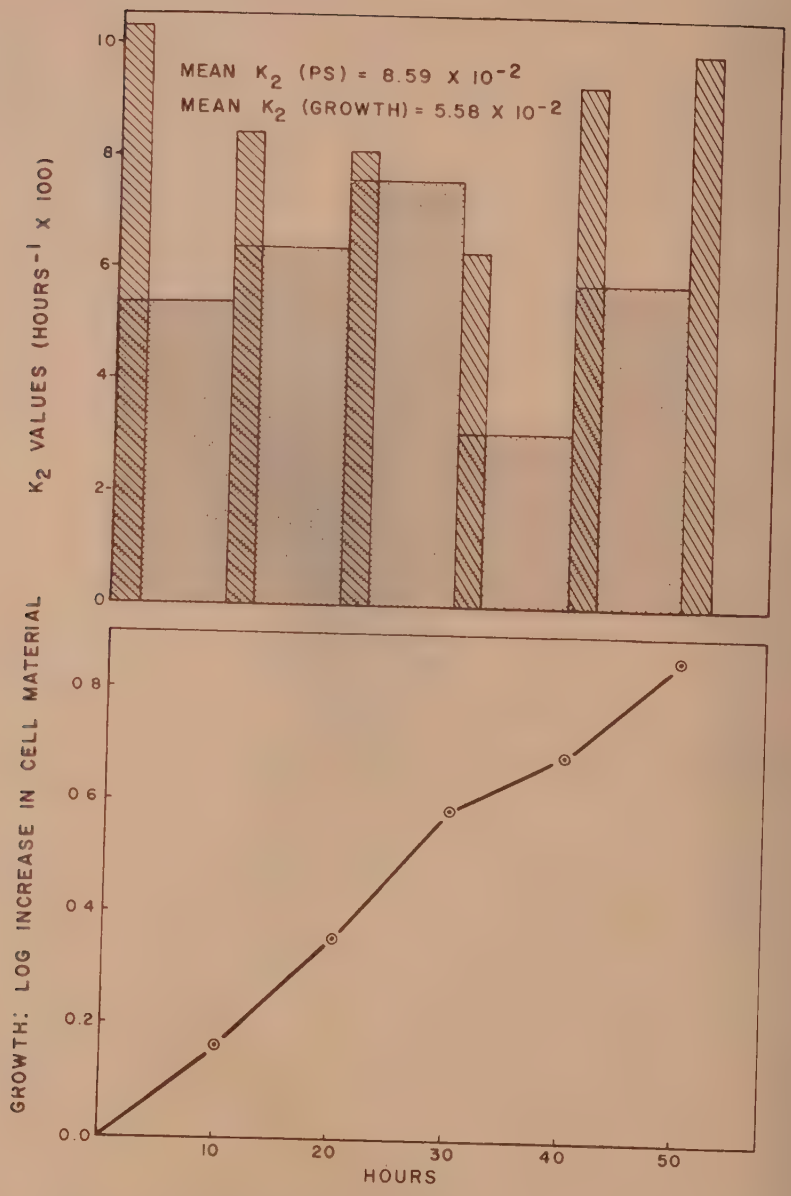


Fig. 4—Comparison of growth and photosynthesis in a culture of Dunaliella primolecta. The upper figure compares photosynthetic $K_2$ values (hatched bars) made at 10-hour intervals with $K_2$ values (stipled bars) calculated from increases in all material during each 10-hour interval. The lower figure shows the growth of the culture as measured by increases in cell concentration, optical density, organic nitrogen, organic carbon, and dry weight. The increase in each growth parameter was calculated relative to that at the beginning of the experiment; the points represent the logarithms of the mean of these relative increases.

presumably remains constant. Dark uptake is relatively more important and dark bottles should certainly be incubated with illuminated ones. Excretion of carbon-14 may also increase with decreasing light intensity, as is indicated in the experiments reported by Fogg (1958). With decreasing light intensity the P/R ratio decreases and the respiratory correction becomes very important. The estimated corrections that can be applied to obtain net or gross photosynthesis at three different light intensities are shown in Table 3. It should be emphasized that these values are only estimates, and indicate that uncertainties are relatively great at the compensation intensity. It is assumed that a correction for dark uptake was made with a dark bottle. Roughly, one could multiply raw carbon-14 data by 1.15, 1.25, and 2.0 to obtain gross phytosynthesis at the three intensities given in Table 3; similarly, use of the factors 1.05, 1.05, and 1.0 would give rough values for net photosynthesis. In any case such rough values would probably not differ from the true value by an amount greater than the overall experimental and sampling error.

Table 3—Corrections to Apply to Raw Carbon-14 Data to Obtain Net and Gross Photosynthesis at Three Different Light Intensities

| | Intensity | | |
|---|---|---|---|
| Estimated Correction for: | Saturation (P/R = 10) | Half Saturation (P/R = 5) | Compensation (P/R = 1) |
| Isotope Effect | +5% | +5% | +5% |
| Excretion | +2% | +5% | +10% |
| Respiration (Ryther Correction) | +10 | +20 | +100 |
| Respiration (Steemann-Nielsen Correction) | +6 | +12 | +60 |
| Total Correction for Gross Photosynthesis (after Ryther) | +17% | +30% | +115% |
| Total Correction for Gross Photosynthesis (after Steemann-Nielsen) | +13% | +22% | +75% |
| Total Correction for Net Photosynthesis (after Ryther) | +7% | +10% | +15% |
| Total Correction for Net Photosynthesis (after Steemann-Nielsen) | +3% | +2% | −25% |

Comparisons of carbon-14 uptake (uncorrected for respiration) with net $O_2$ production at subsaturating intensities (Ryther, 1956b) indicated that the two measurements were comparable down to the compensation intensity (Fig. 1). The data of Ichimura and Saijo (1958) are even more convincing evidence that carbon-14 uptake is equivalent to net $O_2$ production (Fig. 2; Fig. 3), especially if their data are corrected for dark uptake. However, carbon-14 uptake is less than net $O_2$ production at intensities that are one-half to one-quarter of saturating for Lake Harunako. Carbon-14 uptake is greater than net $O_2$ production at the compensation point.

In preliminary experiments (Thomas, unpublished), we also found that uncorrected carbon-14 uptake at or below the compensation point for net $O_2$ evolution was greater than net $O_2$ evolution, and that photosynthetic tracer fixation was greater than dark fixation. However, at such low intensities, as is indicated in Tables 1 and 3, all corrections become so much more uncertain, that one cannot attach much significance to carbon-14 data.

## INTRACELLULAR NUTRIENT LEVEL

### The Effects of Incipient Nutrient Deficiency on Carbon-14 Measurements

When healthy algal cells are transferred to a nutrient-deficient medium, the intracellular concentration of the nutrient decreases. In nitrogen-deficient Scenedesmus, this decrease was exponential with time and a minimum level (one-fourth the normal concentration) was reached after about 5 days of deficiency (Thomas and Krauss, 1955). With nitrogen-deficiency, a period

of incipient deficiency, when the concentration within the cells dropped rapidly, could be distinguished from extreme deficiency, when a minimum nutrient level was reached. When Scenedesmus cells were transferred to phosphorus-deficient medium, the decrease in intracellular phosphorus was not so rapid as with nitrogen deficiency. After 11 days of phosphate deficiency, the cells still contained half the original phosphorus (Thomas, 1954). Incipient phosphorus-deficiency is less easily distinguished from extreme deficiency. Arbitrarily we can suggest that the first few days of deficiency of a nutrient represent incipient deficiency, as contrasted with extreme deficiency. Extreme deficiency is characterized by minimal intracellular nutrient levels, and occurs after these first days.

Assuming that deficiency has little or no influence on correction of carbon-14 data for the isotope effect, we can proceed to examine the effects of deficiency on the other corrections. A correction for dark uptake should be made by incubating a separate darkened bottle. This is especially important if nitrogen deficiency is suspected, since increased dark uptake due to N-deficiency was found by Steemann-Nielsen and Al Kholy (1956). If the increased excretion of labeled material found by Fogg (1958) in an oligotrophic lake as compared to a eutrophic lake is due to deficiency rather than diminished illumination, it may be necessary to correct for excretion in oligotrophic waters. Certainly more research on the effects of deficiency on excretion should be done.

The effects of deficiency on photosynthesis and respiration have been reviewed by Pirson (1955). Photosynthesis at saturating intensities is inhibited by any mineral deficiency, but respiration generally remains constant or may increase. Thus, the P/R ratio decreases as deficiency progresses and correction for respiration will increase.

Ryther (1954b) first considered this decrease in the P/R ratio in comparing carbon-14 uptake with $O_2$ evolution. His results are shown in Figure 5, and indicate that, as nutrients become deficient, the carbon-14 data (uncorrected for respiration) are equivalent to net $O_2$ evolution. Incipient deficiency probably occurred from about the sixth to the tenth day and the last measurement probably represents photosynthesis by extremely deficient cells. One cannot tell from the description of this experiment exactly what element was deficient; presumably both nitrogen and phosphorus were deficient. Similar studies by Steemann-Nielsen and Al Kholy (1956) appear to refer to extreme deficiency and will be discussed below.

We have investigated the effects of nitrogen deficiency on carbon-14 measurements (Thomas, unpublished). Generally, with Dunaliella cells in the beginning stages of deficiency, uncorrected carbon-14 uptake was about 90% of net $O_2$ evolution, but also did not differ significantly from gross $O_2$ evolution. Although cell division ceased during incipient nitrogen deficiency, the culture continued to synthesize organic material, since both dry weight and organic carbon accumulated. $K_2$ values calculated from growth measurements did not differ significantly from those calculated from photosynthesis during incipient deficiency. During deficiency, dark uptake of carbon-14 increased, but this increase may be due to bacterial contamination in the aquarium culture rather than to deficiency per se.

Three comparisons of carbon-14 uptake and $O_2$ evolution during incipient phosphorus deficiency were also made. In one experiment carbon-14 uptake was much less than net $O_2$ evolution. In the other two comparisons the carbon-14 value was intermediate between net and gross $O_2$ evolution, and could not be distinguished from either $O_2$ measurement.

### Carbon-14 Measurements with Extremely Nutrient-Deficient Algal Cells

Algal cultures that are extremely nutrient-deficient contain a minimum intracellular nutrient concentration and have ceased to grow. The P/R ratio in such cultures is generally less than 3, at least, and can be less than 1 if the culture is dying. Ryther (1954b) showed that when the P/R ratio was nearly 1.0, uncorrected carbon-14 uptake was quite comparable with net $O_2$ evolution (see Figure 5, measurement at 30 days). Gross $O_2$ production was several times net production. The results given for phosphorus and nitrogen deficient Chlorella cells by Steemann-Nielsen and Al Kholy (1956) indicate that the carbon-14 method yields results that are intermediate between gross and net $O_2$ evolution. Considering the relative errors of their measurements and the uncertainty of the photosynthetic quotient they used, it is difficult to determine which $O_2$ value is more comparable to carbon-14 uptake.

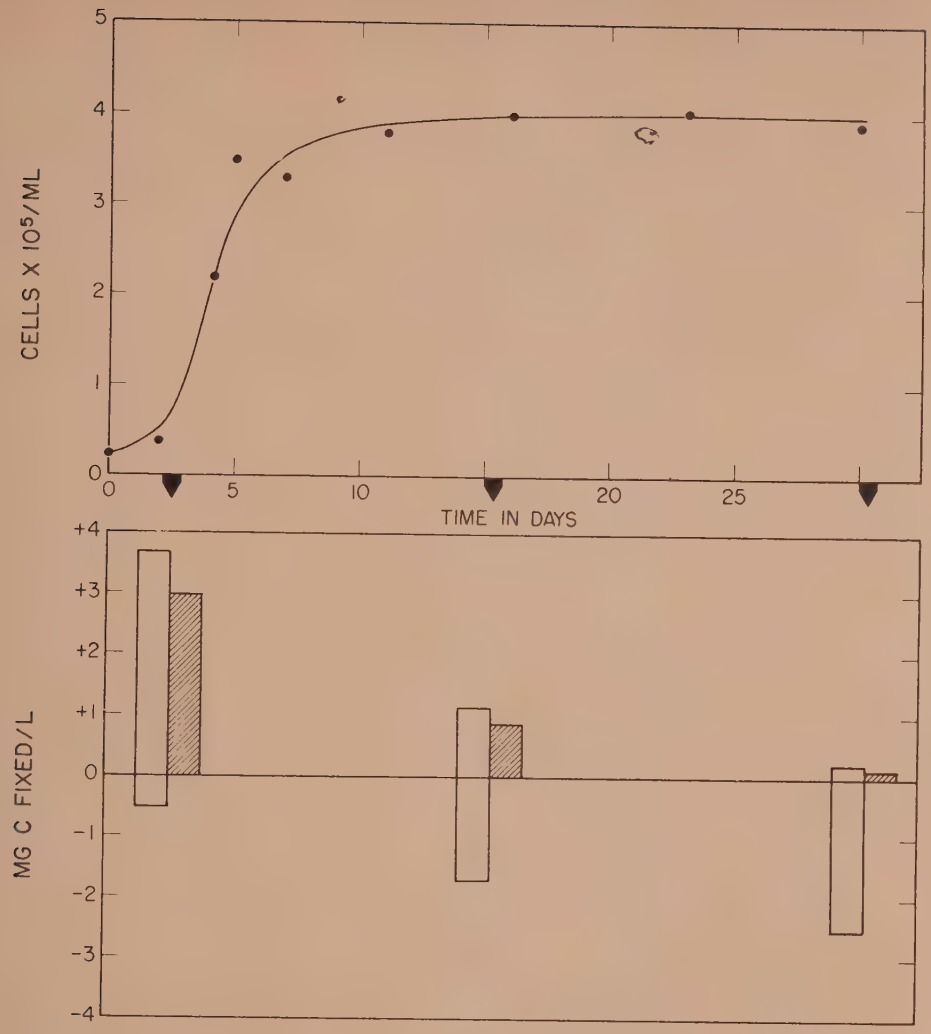


Figure 5— Photosynthesis measured by oxygen production (clear bars) and carbon-14 uptake (hatched bars) in a nutrient-deficient, pure culture of marine Chlamydomonas. Upper figure represents growth of culture determined by cell counts. (Reproduced from Ryther, 1954)

In our laboratory (Thomas, unpublished) we continued our nitrogen deficient Dunaliella cultures from incipient to extreme deficiency. The P/R ratio dropped to 2, and the intracellular nitrogen concentration reached a minimum level. In five comparisons of carbon-14 uptake (uncorrected for respiration) with $O_2$ production, the carbon-14 values were 80-100% of the net $O_2$ value, and 40-70% of the gross value. Uncorrected carbon-14 uptake was significantly greater than gross $O_2$ production. When one of these deficient cultures was continued even further, the P/R become less than 1. Under these very extreme conditions, carbon-14 uptake was still positive, but could not be compared with either $O_2$ measurement, due to analytical errors in the latter measurement that were nearly equivalent to respiratory and photosynthetic changes. Extreme phosphorus deficiency was not studied.

The above results refer only to nitrogen and phosphorus deficiency. Various enrichment experiments have indicated that purines and pyrimidines (Jones and Thomas, 1958) iron (Menzel and Ryther, 1961a), manganese (Harvey, 1947), and, for diatoms, silicon (Thomas, 1959) may limit phytoplankton production. At least, the addition of such substances to water samples can stimulate growth or production. Furthermore, the requirement of various phytoplankton species for organic growth factors (reviewed by Provasoli, 1958) suggests that such

factors may at times be deficient in the sea. At present we have no information on the effects of deficiencies of nutrients other than nitrogen and phosphorus on carbon-14 uptake.

### Recovery From Nitrogen Deficiency

After extreme nitrogen deficiency was established, we added nitrate to Dunaliella cultures (Thomas, unpublished). In one experiment, after 21 hours of recovery, significant growth had occurred, cell nitrogen increased to the concentration characteristic of healthy, growing cells, and the P/R increased from 1.9 to 3.6. After recovery, carbon-14 uptake was intermediate between and equivalent to either net or gross $O_2$ production. The mean $K_2$ value for growth during recovery was 0.0324 $hours^{-1}$; that for photosynthesis after recovery was 0.0312 $hours^{-1}$. In another recovery experiment, similar changes in the P/R ratio and intracellular nitrogen level were observed. Again carbon-14 uptake was intermediate between, and equivalent to, either $O_2$ production measurement. Growth constants were not calculated for this experiment.

### Nutrient Deficiency in the Sea

Evidence from enrichment experiments referred to above shows that nutrient deficiency occurs in the sea. Furthermore, nutrient concentrations in surface water may sometimes be below the concentration that limits the growth rate of phytoplankton cultures (Thomas, unpublished data, and others). However, data concerning the degree of deficiency (incipient or extreme) that exists in natural phytoplankton populations is very sparse.

Steemann-Nielsen and Al Kholy (1956) pointed out that under conditions of extreme deficiency, where the P R ratio was less than 2, the algal population would not persist, and they suggested such extreme conditions would not occur (see also Strickland, 1960). The same authors showed that extreme nitrogen deficiency resulted in an increase of dark carbon-14 fixation to 37% of the light-saturated rate. However, in the North Atlantic and off Greenland, only a few determinations resulted in dark fixation greater than 10% of the light-saturated rate (Steemann-Nielsen, 1960). Thus, it seems doubtful that the population was extremely nitrogen deficient.

More convincing evidence against the occurrence of extreme nitrogen deficiency in the sea was obtained by Yentsch and Vaccaro (1958). They showed that the ratio of carotenoid pigments of chlorophyll-a increased in nitrogen-deficient cultures from a value of 0.22 to 0.40 for nitrogen-enriched cultures to 0.59 to 0.67 for the most deficient cultures. In Atlantic coastal waters ratios of 0.15 to 0.55 were observed, which suggested that natural populations were not as deficient as extremely deficient laboratory cultures. However, it should be noted that a few high ratios (>0.60) were reported from the same waters by Ketchum, et al. (1958a). These authors also showed that there was no clear relationship between these pigment ratios and the ratio of net to gross photosynthesis in Atlantic coastal waters.

In extremely nitrogen deficient Dunaliella cultures, the ratio of cell carbon to cell nitrogen increased to approximately 15 as compared with 5 to 7 in healthy growing cultures (Thomas, unpublished). The measurement of the C/N ratio of phytoplankton net hauls and more calculations of pigment ratios (from data already on hand) might provide additional insight into the intracellular nitrogen status of natural populations.

## SUMMARY AND CONCLUSIONS

Of the four corrections that may be applied to raw carbon-14 data, three of them (for isotope effect, dark uptake, and excretion) are applicable for correcting carbon-14 data to both net or gross production. The theoretical correction for the isotope effect is about +5% and this value is found for long-term growth of algal cultures; the correction may be somewhat larger for photosynthesis periods of a few hours. To determine the isotope effect more precisely, direct comparisons of carbon-14 uptake with carbon assimilation would be needed for periods approximating those used in routine productivity measurements. A correction for dark uptake of tracer carbon is conveniently made by incubating darkened bottles with illuminated ones.

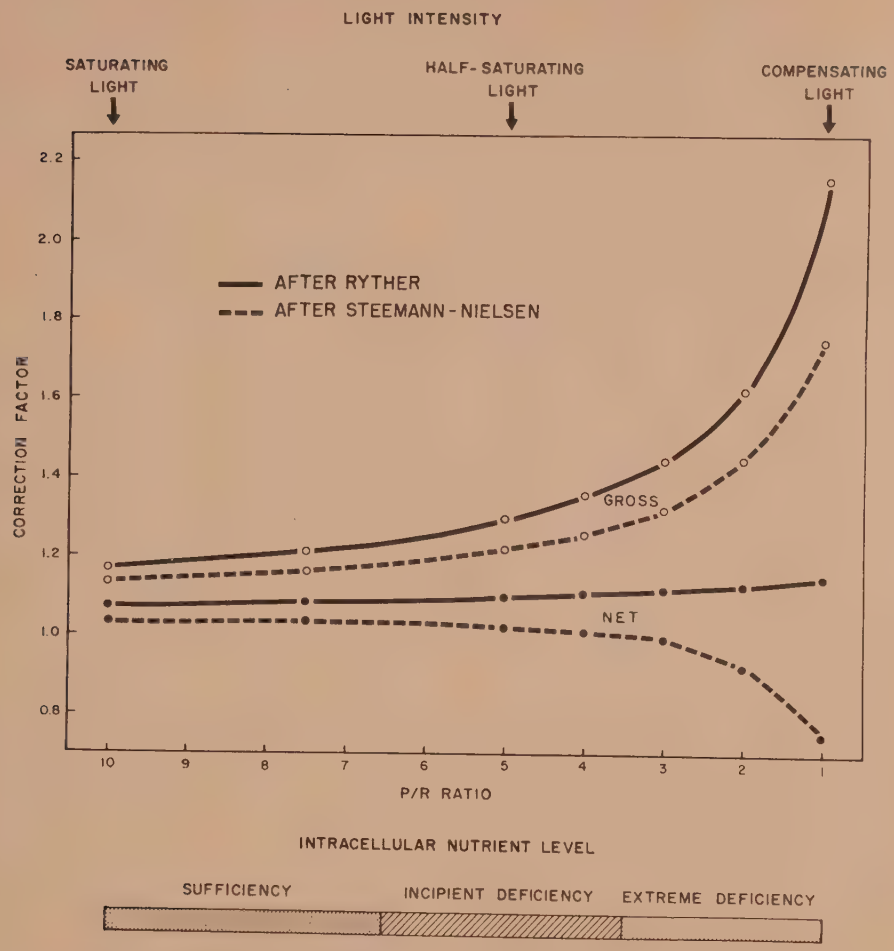


Figure 6— Factors by which raw carbon-14 data may be multiplied to obtain net (closed circles) or gross (open circles) photosynthesis at different P/R ratios. The factors are calculated assuming 100 percent intermixing of respiration with photosynthesis (solid lines— Ryther, 1956), or assuming 60 percent intermixing (dashed lines— Steemann-Nielsen, 1955). Also shown are light intensities and intracellular nutrient levels which would result in given P/R ratios.

Further investigation of factors affecting dark uptake may provide a powerful tool for measuring the nutritional status of natural populations. Investigations of excretion of previously labeled organic material and the rupture of algal cells during filtration have just begun. Present evidence indicates that this correction is just a few percent. Nutritional deficiency or subdued illumination may profoundly affect the amount of excretion, but much more research is needed on this problem.

The application of the fourth correction, for respiration (if a value for gross photosynthesis is desired), is dependent upon the degree of intermixing of respiration and photosynthesis and also upon the P/R ratio. The relationship between the P/R ratio and the overall correction factors to use to obtain either net or gross photosynthesis is summarized in Fig. 6. Correction factors assuming 100% intermixing of respiration (Ryther) and 60% (Steemann-Nielsen) are given. The isotope effect correction is included in the factor (assuming a +5% correction under all conditions); a correction factor for excretion is also included which is assumed to vary from +2% at a P/R ratio of 10 to +10% at a P/R ratio of 1. No correction is included for dark uptake; a separate dark bottle determination is assumed. As is indicated by Figure 6, if

one used a mean factor between Ryther's or Steemann-Nielsen's a calculation of either net or gross photosynthesis would scarcely be in error by an amount greater than experimental or sampling errors of the carbon-14 method, even down to a P/R ratio of 2. This range of P/R values covers nearly all conditions under which the bulk of phytoplankton photosynthesis is carried out. At P/R ratios less than 2, the uncertainties increase greatly.

Under conditions where the P/R ratio is high, the difference between net and gross photosynthesis is small. Carbon-14 results (uncorrected for respiration) agree with either net or gross $O_2$ evolution within experimental error, although carbon-14 values generally are closer to net $O_2$ values than to gross values. When both growth measurements and production measurements are carried out under similar conditions of illumination, growth rate constants ($K_2$) calculated from various growth measurements are in agreement with similar constants calculated from organic carbon and photosynthetic measurements.

The P/R ratio decreases with decreasing illumination. At subsaturating light intensities, carbon-14 uptake (uncorrected for respiration) is generally equivalent to or somewhat less than net $O_2$ evolution. At the compensation intensity, carbon-14 uptake is still positive. Incipient nutrient deficiency also decreases the P/R ratio and carbon-14 uptake is closest to net $O_2$ evolution, but also does not differ greatly from gross $O_2$ evolution. Growth and photosynthesis are quite comparable. Extreme deficiency greatly decreases the P/R ratio and carbon-14 uptake (uncorrected for respiration) is in good agreement with net $O_2$ evolution, but not with gross production.

Various means of establishing the degree of intracellular nutrient deficiency in natural populations have been considered. Pigment ratios, carbon/nitrogen ratios, and dark uptake measurements could be used. It would be of great interest to know if deficiencies occur in nature that are as extreme as those found in really deficient cultures.

## ACKNOWLEDGEMENTS

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# Thermal Gradient Incubators for Small Aquatic Organisms[1]

Water or air baths have generally been used to control the temperature of cultures of aquatic organisms; these require a separate bath for each temperature. Halldal and French (1956, 1958) subjected algae to a continuous temperature gradient with a device that required only two water baths. Algae were grown on an agar surface poured on an aluminum plate; a thermal gradient was established along one axis of the plate and a light-intensity gradient along the other. Their equipment was useful for determining algal responses to light and temperature, but could not be used for liquid cultures. Adaptation of the thermal gradient principle to liquid cultures was suggested by Halldal and French (1956), and such devices were constructed for bacterial cultures in test tubes by Oppenheimer and Drost-Hansen (1960); Landman, Bausum, and Matney (1962); and Cannefax (1962). Eppley and MaciasR (1962) used a gradient block for liquid cultures of algae.

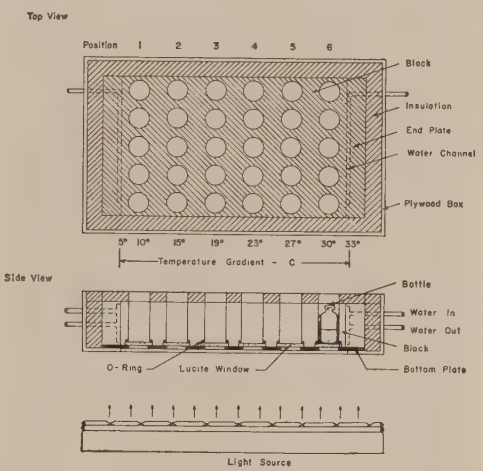


Fig. 1. Schematic drawing of the block used for culturing algae, block A.

[1] Contribution from the Scripps Institution of Oceanography, University of California, San Diego, New Series. Marine Foraminifera Laboratory Contribution No. 42. This research was supported by Contract No. 14-17-0007-28 between the U. S. Bureau of Commercial Fisheries and the Scripps Institution of Oceanography; by Contracts NONR 275(18) and NONR 2216(00) between the Office of Naval Research and the Scripps Institution of Oceanography; and by American Petroleum Institute Project 51. The authors are grateful to Mr. Harold Hill for helping design these devices, to the shop personnel who constructed them, and to Mr. Rudy Fidler for technical assistance.

Table 1. *Dimensions and other characteristics of thermal gradient blocks for incubating algae, bacteria, and foraminifera*

| Block | Use | Overall dimensions inches (cm*) Length | Width | Thickness | Hole dimensions inches (cm*) Diameter | Depth | Center-to-center spacing | Total number of holes | Number of replicates at each temperature | Number of temperature levels | Culture containers | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Algae | 26 (66) | 14.5 (36.8) | 3 (7.6) | 2 (5.1) | 3 (7.6) | 4 (10.2) | 30 | 5 | 6 | Reagent bottles (67 ml) Conical flasks (50 ml) | Large gradient across holes; block illuminated from below |
| B | Bacteria | 38 (96.5) | 12 (30.5) | 4.75 (12.1) | 0.8125 (2.1) | 4.25 (10.8) | 1.25 (3.2) | 162 | 9 | 18 | Test tubes (20 mm diameter) | Small gradient across holes; best temperature control of three blocks |
| C | Foraminifera | 36 (91.4) | 12.75 (32.4) | 3 (7.6) | 2.25 (5.7) | 0.75 (1.9) | 4.25 (10.8) | 32 | 4 | 8 | Petri dishes (55 mm diameter) | Large gradient across holes; shallow holes; cultures could be illuminated from above |

* Approximate metric equivalent.

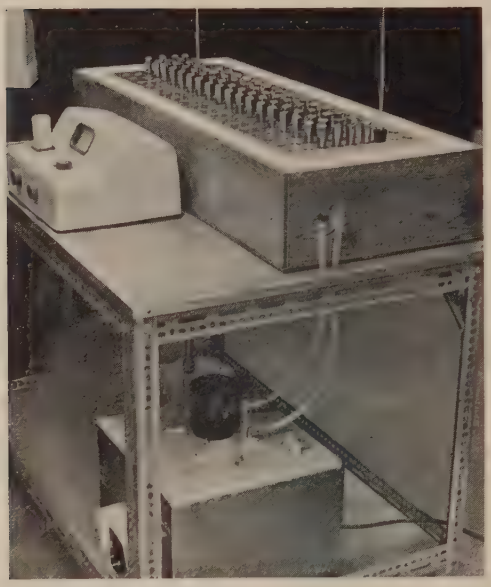

FIG. 2. Photograph of the block and associated water baths used for culturing bacteria, block B.

FIG. 3. Photograph of the block and associated water baths used for culturing foraminifera, block F.

The present paper describes three different thermal gradient blocks for simultaneously incubating liquid cultures of algae, bacteria, and foraminifera at several temperatures. A thermal gradient was established by circulating cold water through a channel in one end of an aluminum block and warm water through a similar channel in the other end. Liquid cultures, in appropriate glass or plastic vessels, were maintained at different temperatures by placing the containers in holes drilled in the block.

The blocks were constructed of aluminum alloy and were insulated with styrofoam plastic. Their dimensions and other characteristics are given in Table 1. In block A (Fig. 1), the holes for liquid culture vessels were bored completely through the block. At the bottom of each hole a slightly larger recess held a ¼-inch (ca. 0.64 cm) clear lucite window through which light was supplied to the culture. To prevent leakage, neoprene "O" rings sealed the window to the block. The construction of the other blocks (Figs. 2 and 3) was similar, but the holes were not drilled completely through them, and they also contained thermometer wells.

The channels through which water was

TABLE 2. *Temperatures in bottles containing* Gymnodinium *cultures incubated in holes in thermal gradient block A. (Block not shaken)*

| Time in hours | Temperature, C | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cold bath | Position along gradient | | | | | | Warm bath |
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| 0 | 5.3 | 9.7 | 14.0 | 18.7 | 22.5 | 26.0 | 29.7 | 33.0 |
| 18 | 5.3 | 10.3 | 14.6 | 19.2 | 22.8 | 26.7 | 29.8 | 33.1 |
| 42 | 5.3 | 10.1 | 15.0 | 19.4 | 22.8 | 26.7 | 30.0 | 33.3 |
| 66 | 5.3 | 10.4 | 15.1 | 19.6 | 23.2 | 27.0 | 30.3 | 33.2 |
| Mean temperature | 5.3 | 10.1 | 14.7 | 19.2 | 22.8 | 26.6 | 30.0 | 33.1 |
| Range | 0.0 | 0.7 | 1.1 | 0.5 | 0.7 | 1.0 | 0.6 | 0.3 |

FIG. 4. Detail of end plate from block A showing double spiral channels and neoprene "O" ring.

circulated were especially designed so that the temperature would be uniform over the entire end of the block. Each channel was milled into the inner face of an end plate (Fig. 4) in the form of a double spiral. The inward and outward spirals were always close to each other, and a countercurrent exchange of heat occurred between adjacent spirals. The plates were bolted to each end of the block; a neoprene "O" ring prevented leakage.

When water was circulated through each channel at a rate of 2 to 3 liters per min, the gradient in these blocks was established and stabilized after approximately one hr. The gradient was linear, or approximately so. Gradients across each hole were expected. Their magnitude depended upon the size of the hole and upon the overall gradient in the block. Gradients across holes could be eliminated by shaking the block on a reciprocal shaker. Due to the design of the end plate channels, at a given position along the gradient, there was very little temperature variation (maximum, 0.8 C) among adjacent holes. To transfer heat from the block to the cultures, distilled water was placed in each hole; thus, each hole was in effect a small, separate water bath. During long experiments required for algae and foraminifera, temperatures in blocks A and F were reasonably constant (Tables 2, 3, and 4). For the short time (12 hr) required for experiments with bacteria in block B, the maximum variation in a single hole was 0.03C.

These blocks are versatile tools for studying the effects of temperature on aquatic organisms. Although the temperature may not be as constant as that in well-regulated water baths (Tables 2, 3, and 4), a single block can replace a whole series of such

TABLE 3. *Temperatures in bottles containing* Chaetoceros *cultures incubated in holes in thermal gradient block A. (Block shaken)*

| Time in hours | Temperature, C | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cold bath | Position along gradient | | | | | | Warm bath |
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| 0 | 5.4 | 10.5 | 15.1 | 19.7 | 23.4 | 26.9 | 30.3 | 33.0 |
| 7 | 5.4 | 10.2 | 14.2 | 19.4 | 23.1 | 26.8 | 30.0 | 33.1 |
| 23 | 5.4 | 10.4 | 14.9 | 19.4 | 23.5 | 26.7 | 30.1 | 33.1 |
| 31 | 5.4 | 10.4 | 14.7 | 19.4 | 23.5 | 26.7 | 30.1 | 33.1 |
| 47 | 5.3 | 10.1 | 14.6 | 19.1 | 23.0 | 26.5 | 29.9 | 33.0 |
| Mean temperature | 5.4 | 10.3 | 14.7 | 19.4 | 23.3 | 26.7 | 30.1 | 33.1 |
| Range | 0.1 | 0.4 | 0.9 | 0.6 | 0.5 | 0.4 | 0.4 | 0.1 |

TABLE 4. *Temperatures at various positions along block F over indicated time periods*

| Time in hours | Temperature, C | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Position along gradient | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 0 | 30.8 | 31.7 | 32.6 | 33.6 | 34.5 | 35.6 | 36.7 | 37.9 |
| 13 | 31.1 | 32.0 | 33.0 | 34.0 | 35.0 | 36.0 | 37.0 | 38.0 |
| 37 | 31.0 | 32.0 | 32.9 | 34.0 | 35.0 | 36.0 | 37.0 | 38.0 |
| 60 | 31.0 | 32.0 | 33.0 | 34.0 | 35.0 | 36.0 | 37.0 | 38.1 |
| 84 | 31.0 | 31.9 | 32.8 | 33.8 | 34.8 | 35.8 | 36.9 | 38.0 |
| 108 | 31.0 | 32.0 | 33.0 | 34.0 | 35.3 | 36.4 | 37.3 | 38.0 |
| Mean temperature | 31.0 | 31.9 | 32.9 | 33.9 | 34.9 | 36.0 | 37.0 | 38.0 |
| Range | 0.3 | 0.3 | 0.4 | 0.4 | 0.8 | 0.8 | 0.6 | 0.2 |

baths. It is also easy to shift from one temperature range to another or to expand the range. In these blocks, several cultures can be incubated simultaneously, and the interactions between temperature and other environmental factors may be readily investigated. We have used these blocks for many experiments on the effects of temperature on phytoplankton, bacteria, and foraminifera. These results will be reported elsewhere.

WILLIAM H. THOMAS
HAROLD L. SCOTTEN[2]
JOHN S. BRADSHAW

*University of California, San Diego*
*Scripps Institution of Oceanography*
*La Jolla, California*

[2] Present address: Douglas Marine Laboratory, University of Alaska, Douglas, Alaska.

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BY

KLAUS WYRTKI

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# THE HORIZONTAL AND VERTICAL FIELD OF MOTION IN THE PERU CURRENT

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KLAUS WYRTKI

ABSTRACT

Using data from hydrographic stations taken in the area off Peru during Step-I Expedition in October–November, 1960, and wind stress data for the same season, the relative geostrophic transports and the Ekman transports are calculated. The motion is considered as stationary, lateral friction is neglected, and vertical friction in the Ekman layer is confined to 100 m depth. With the assumption that the vertical motion at 3,000 m depth vanishes, the absolute topography of the sea surface and the absolute transports can be determined, as well as the vertical motions. The determined absolute topography of the sea surface does not deviate more than ±1.0 cm from the topography relative to 1,000 decibar. There is no continuous "layer of no motion" or layer of no horizontal divergence in this region, but the layer near 700 m depth exhibits the smallest divergence of the horizontal flow.

Upwelling off the coast is mostly restricted to depths of less than 100 m, but ascending movements in greater depths and farther offshore are at least of the same magnitude as the near surface upwelling and are likely to be important for maintaining this upwelling. The flow near the coast in layers between 100 m and 400 m depth is highly convergent and supplies the upwelling on top of this layer as well as the sinking at its bottom. South of 15° S. upwelling is supplied by Subantarctic Water flowing north with the Peru Coastal Current, and north of 15° S. by Equatorial Subsurface Water flowing south with the Peru Countercurrent. It is shown that the Peru Countercurrent and the Peru Undercurrent, although both flow south, are different currents.

## INTRODUCTION

The circulation along the eastern boundaries of the oceans and the related upwelling have received considerable attention during recent years. A general discussion of these phenomena has been given by Wooster and Reid (1963) in their comparative treatment of eastern boundary currents in the different oceans. One of the major upwelling areas in the oceans is situated off the coast of Peru and is related to the Peru Current flowing equatorward. To study this area more intensively, Step-I Expedition (Scripps Institution of Oceanography, 1961) was undertaken in September through December, 1960, in the region of the Peru Current under the leadership of W. S. Wooster. This expedition covered the area between 5° S. and 24° S. and as far as 2,000 km offshore, in contrast to earlier expeditions which restricted their activities to the coastal zone. This expedition was designed to provide information on the interaction and relation between horizontal circulation in the system of the Peru Current and upwelling along the coast. This implies, it was thought, that the upwelling along the coast might not be a local, small-scale feature, but an integral process of the circulation in the eastern parts of the oceans.

The study is an attempt to investigate quantitatively the relation between the coastal upwelling and the horizontal circulation. Horizontal and vertical flow are integral parts of the same field of motion, and in general they cannot be treated separately. This is especially true in regions of upwelling where the effects of vertical movements are comparable with the effects of horizontal flow. This report is devoted to the study of their interaction and their respective contributions to

circulation, and a scheme of calculations is designed to determine the three-dimensional field of motion.

The following questions, which are basic to an understanding of the upwelling off Peru, are discussed:

1. Where does the upwelling water come from?
2. How is it brought underneath the upwelling area?
3. What is the vertical and horizontal distribution of vertical motion?
4. How large is the area that influences directly and indirectly the upwelling along the coast?

Problems not discussed in this paper are the influence of transient wind systems on the upwelling as well as its periodic and random fluctuations, and the small-scale features and fine structure of the upwelling.

Upwelling is a term widely used in oceanography although a precise definition has not yet been given. As pointed out above, vertical movements are integral parts of the circulation in the oceans, although they will be chiefly connected with meridional flow and along boundaries. Consequently, ascending motions in any depth cannot be considered as upwelling unless they reach the surface: this means that water from some depth, previously not at the surface, is brought to the surface. There must also be a distinction between upwelling, as a process, and the effects of upwelling. In most parts of the oceans upwelling will result in a lowering of sea-surface temperatures, but in the Arctic or Antarctic the reverse may be true. Wind-induced vertical mixing, deepening the wind-stirred layer, may also produce a lowering of the sea-surface temperature and other effects similar to upwelling. Such an effect, however, can not be considered as upwelling. Where upwelling and wind-stirring will be effective simultaneously, it may be difficult to separate these two processes. In this case another criterion of upwelling can be applied, namely that the water reaching the surface must be removed horizontally from the upwelling area in order to maintain this process for an appreciable time.

Upwelling will therefore be considered as an ascending motion by which water from subsurface layers, usually from depths not exceeding 100–200 m, is brought to the surface *and* is removed by horizontal flow from the area of upwelling.

## THEORETICAL BACKGROUND

For the calculation of the horizontal and vertical field of motion it will be assumed that the horizontal motion is composed of a geostrophic flow, prescribed by the topography of the sea surface and the distribution of density, and an Ekman flow in the surface layer. The neglect of inertial and lateral frictional terms seems to be justified in the range of the Peru Current because current velocities are usually small compared with swift ocean currents such as western boundary currents, where these terms have to be taken into account. This important difference in the advection of vorticity in western and eastern boundary currents has been clearly emphasized by Carrier and Robinson (1962). Accelerations due to transient wind systems will be of some importance, especially along the coast, but it seems to be difficult to assess their influence. Their investigation would require a network of observations in a small area, repeated in short intervals. This study, however, considers a larger area and a longer period, and therefore a steady state will be

assumed and accelerations neglected. The vertical motion is assumed to be due to the convergence and divergence of the horizontal flow and to be zero at the surface and at the bottom of the ocean.

The component $v_N$ of the velocity normal to a curve $s$, where $s$ is the coordinate along the curve (fig. 1, *a*), is at any depth $z$ given by

$$\rho f v_N = -\rho g \frac{\partial h}{\partial s} - \frac{\partial}{\partial s} \int_0^z \rho g \, dz - \frac{\partial \tau_s}{\partial z}, \tag{1}$$

where $\rho$ is the density, $\tau_s$ the stress component parallel to and in the direction of $s$, $h$ the height of the sea surface, $g$ the acceleration due to gravity, and $f$ the Coriolis parameter depending on latitude $\phi$ (south latitude positive). The equation of

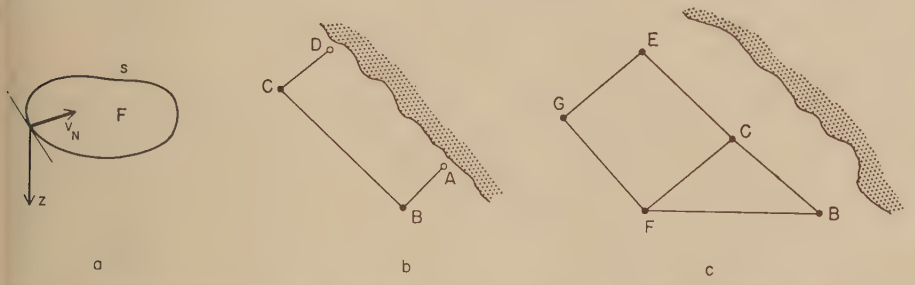


Fig. 1. *a*. Notations used in the equations. *b*, *c*. Samples of station network used along the coast (*b*) and offshore (*c*).

continuity requires that the integral of $v_N$ over the cylindrical surface containing the closed curve $s$, and from the surface $z = 0$ to the bottom $z = B$, vanishes, if the obvious boundary conditions that there is no mass flux across the sea surface and across the bottom are applied:

$$\int_s \int_0^B v_N \, dz \, ds = 0 . \tag{2}$$

The condition (2), which is equivalent to the equation of continuity, allows, together with equation (1), the determination of the absolute topography of the sea surface $h$, if the wind stress and the distribution of density are observed and a lateral boundary condition is applied. Consequently the entire field of horizontal and vertical motion can be derived. The vertical velocity $w$ in the depth $z$, for instance, is given by

$$w_{(z)} = -\frac{1}{F} \int_s \int_0^z \frac{1}{f} \left( g \frac{\partial h}{\partial s} + \frac{1}{\rho} \frac{\partial}{\partial s} \int_0^z \rho g \, dz + \frac{\partial \tau_s}{\partial z} \right) dz \, ds , \tag{3}$$

where $F$ is the area enclosed by the curve $s$.

The use of equations (1) and (2) is, however, equivalent to the use of Sverdrup's equation

$$\beta M_y = \mathrm{curl}_z \, \tau, \tag{4}$$

where $M_y$ is the meridional component of the transport, $\tau$ the wind stress at the sea surface, and $\beta$ the meridional variation of the Coriolis parameter. This equation has until now only been used to derive models of the circulation of an entire

ocean and, although two-layer models have been used, the distribution of density has never been used explicitly. Consequently, no details of the vertical distribution of velocity could be derived. The calculations carried out in this report are in fact an extension of a method to determine the "layer of no meridional motion" given by Stommel (1956), who pointed out that it could be extended for an entire ocean by the use of the equation of continuity.

In practice the vertical distribution of density is not known along the entire length of the curve $s$, but only at discrete points. Therefore, for practical purposes a network of hydrographic stations is used, in which, starting from the coast, the topography of the sea surface $h$ of the next offshore station is successively determined. Along the coast the natural boundary condition, where the transport across the coastline vanishes, has to be applied as in the case of Sverdrup's equation.

Difficulties arise because most of the hydrographic stations do not extend to the bottom and it is not easy to allow for a complicated bottom topography. An appreciable number of stations of the Step-I Expedition do, however, extend to depths greater than 3,000 m. Therefore the calculations have been extended to a depth of 3,000 m, and it has been assumed that the vertical velocity at 3,000 m is zero. This means it is assumed that the flow between 3,000 m and the bottom is free of divergence. Even if this assumption is not strictly fulfilled it will not seriously affect the derived flow pattern and the vertical motion in the upper 1,500 m, which are of most interest. The ocean bottom in this area is comparatively smooth, with an average depth of approximately 4,000 m. The only major disturbance is the trench along the continent off Peru.

## THE CALCULATIONS

Because it was desirable to extend the calculations as close to the bottom as possible, the network was given by those stations with observations to at least 3,000 m depth (fig. 2). The Ekman transports across all these sections were determined using the average wind stress data given by Hidaka (1958) for the season September–November during which the hydrographic stations were obtained. The wind data were only slightly smoothed and agree fairly well with the wind observations during the expedition, which could not be used because of the greater scattering of individual observations compared with averages. The Ekman transports are shown in figure 2.

Along the coast groups of two deep stations (B and C in figure 1, *b*) and two stations close to shore with observations to 1,000 m (A and D) were chosen to form areas for the calculations. First the total transports (Ekman transports and geostrophic transports relative to 1,000 decibar) across the sections AB and CD were determined. If the height of the sea surface at station B is given, for instance, as the dynamic height relative to 1,000 decibar, the height of the sea level at station C can be calculated using equations (2) and (1) and taking into account that there is no transport across the coastline. This height will usually deviate by a small amount from the dynamic height of this station relative to 1,000 decibar. The determination of the sea level at station C gives also a new reference level for the section BC, which is usually found near 800 m depth. As a consequence of this,

the flow across the smaller sections AB and CD has been adjusted to this new level, giving also the height of the sea surface at stations A and D, and the calculation of the sea level at station C was repeated but usually gave only a slightly different correction. In this way the height of the sea surface at the stations along the coast was progressively determined. It was found that the calculated height at the northernmost station was only 0.4 dynamic cm smaller than the height rela-

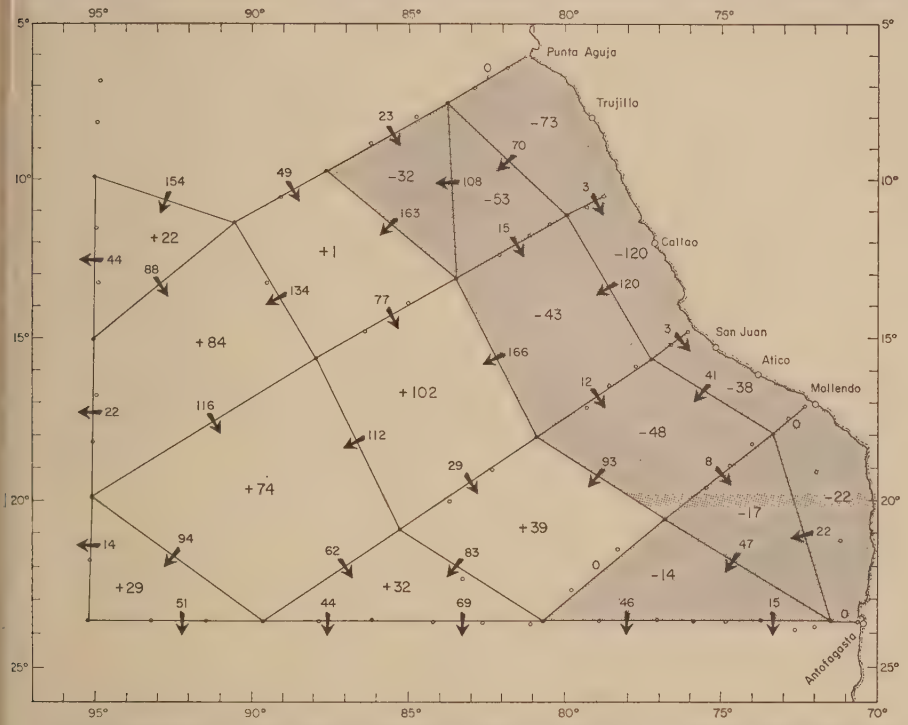


Fig. 2. The network of hydrographic stations of Step-I Expedition: • denotes stations to 3,000 m depth and more, used for calculations; ° denotes stations to 1,000–1,200 m. Ekman transports across the sections formed by the 3,000-m stations in $10^{10}$cm³/sec (100 equals 1 million m³/sec), and the divergences (shaded) and convergences of the Ekman flow.

tive to 1,000 decibar, but this was sufficient to satisfy the boundary condition along the coast.

It should be mentioned that the boundary condition $v_N = 0$ along the coast is applied and fulfilled at any depth $z$, whereas in general theories only the condition $\int_o^B v_N \, dz = 0$ is satisfied along the coastline.

Starting from the deep stations along the coast for which the absolute heights of the sea surface had been determined, a triangle CBF (fig. 1, *c*) to the next offshore stations was formed, and the transports across its three sides were determined according to equation (1). Application of equation (2) resulted in the determination of the height of the sea surface at station F. In exactly the same way the height at station G was determined using a quadrangle ECFG (fig. 1, *c*). In this way the calculations were carried from the coast into the ocean until the heights of the sea

surface of all the deep stations were successively determined. As the dynamic heights relative to 1,000 decibar were used to determine the relative transports, the absolute heights of the sea surface are given by small corrections to the topography of the sea surface relative to 1,000 decibar. These corrections in turn represent the absolute topography of the 1,000-decibar surface and are shown in figure 3. The corrections range from +0.4 cm to −1.2 cm and are very small indeed, although they have appreciable effects on the transports. The topography of the 1,000-

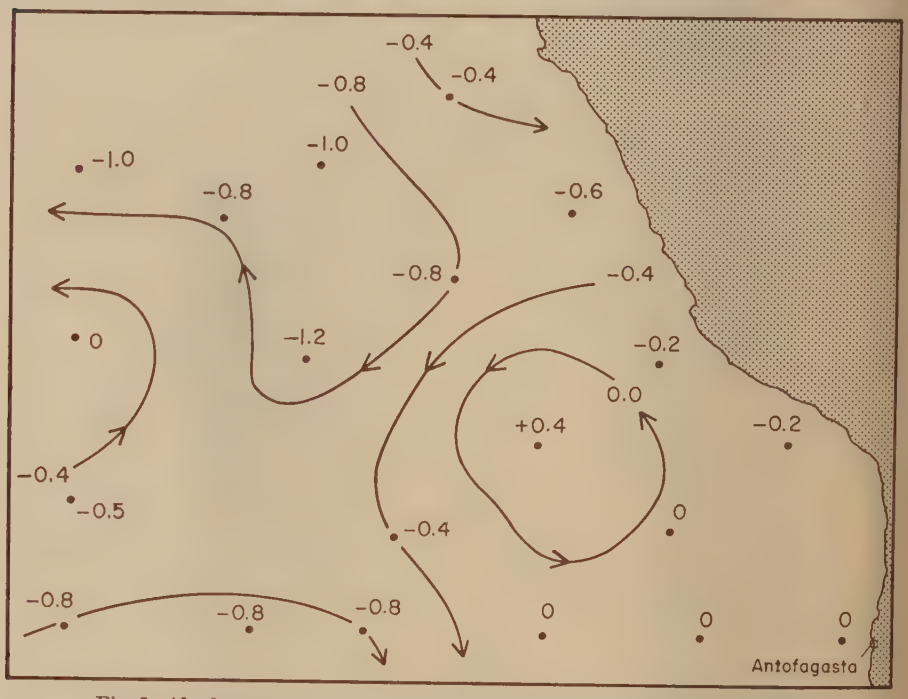


Fig. 3. Absolute topography of the 1,000-decibar surface in dynamic cm with reference to station 50 off Antofagasta.

decibar surface in figure 3 is drawn for every 0.4 dynamic cm and shows a very weak flow from the north to the west and south. The topography of the sea surface relative to 1,000 decibar, which ranges from 114 to 148 dynamic cm in the same region, would only be affected insignificantly by these corrections, so that it can still be taken to represent the geostrophic currents in the upper few hundred meters.

After the absolute topography of the sea surface has been determined in such a way that the transports satisfy equation (2) and the condition that $w = 0$ at $B =$ 3,000 m depth and there is no transport across the coastline, it is possible to determine the entire field of horizontal and vertical motion in this area. For a presentation of the results five layers are selected with some resemblance to the hydrographic structure of the region. These layers are divided by level surfaces at 100, 300, 700, 1,400 and 3,000 m depth. For each of these layers the horizontal

transports across sections between pairs of deep stations are calculated and shown in figures 4–8. In the center of each triangle or quadrangle formed by these sections the convergence or divergence of this layer is given, being the net inflow or outflow of the horizontal motion. In addition, the average vertical velocities across the horizons of 100, 300, 700 and 1,400 m depth are shown for each of the triangles or quadrangles in figures 9, 10, 12, and 13. These velocities were calculated according to equation (3). The transports are given in $10^{10}$cm$^3$/sec (a value of 100 equals 1 million m$^3$/sec). The vertical velocities are given in $10^{-5}$cm/sec (a value of 10 $10^{-5}$cm/sec equals 2.6 meters per month).

With regard to the accuracy of the method, and especially with regard to the accuracy of the value of vertical velocity, it should be borne in mind that observations at oceanographic stations are subject to variations resulting from internal waves and transient motions, which can change the density structure and consequently the calculated geostrophic flow. In Sverdrup's theory the vertical velocity $w_i$ in an intermediate depth is connected with the meridional component of the mass transport $M_{y2}$ below this depth by the relation

$$\rho f w_i = \beta M_{y2},$$

as pointed out by Stommel (1958). Consequently errors in the determination of $M_y$ will directly affect the vertical velocity in the same proportion, but its direction will not be changed, unless the sign of $M_{y2}$ changes. If $M_{y2}$ should be incorrect by 10 per cent, owing to transient changes in the density structure, the same proportional error should apply for the determined value of the vertical velocity $w_i$.

There are no repeated oceanographic stations in this area to estimate the effect of the changing density structure on deep meridional transports and consequently on the calculated vertical velocities, but Wüst (1957) has shown in his critical discussion of the transports in the deep layers of the Atlantic Ocean that such calculations are probably correct within maximal ±10 per cent. Consequently it can be said that an error of this order in $M_{y2}$ and with it an error in $w_i$, as stated above, would not seriously affect the distribution of vertical velocity as long as $M_{y2}$ is large. On the other hand, if $M_{y2}$ is close to zero, a change in the density structure could change the sign of $M_{y2}$ and also that of $w_i$, but this would not be important, since vertical velocities close to zero are not significant. Moreover, a changing density structure at one station in the network would have little effect other than to cause opposite changes of $M_{y2}$ and $w_i$ on both sides of this station. In fact, the use of the equation of continuity which causes the necessary adjustment of the topography of the sea surface, as shown above, has the tendency to suppress influences resulting from disturbed density distributions.

## THE HORIZONTAL FLOW

The Ekman transports across the various sections are given in figure 2 together with the convergence and divergence of the Ekman layer. It is seen that a divergent Ekman layer extends from the coast to about 600–800 km offshore. To the west of it lies an area with convergent Ekman flow. The boundary between the two areas coincides with the position of the maximum wind stress. The transport across this boundary is 4.2 million m$^3$/sec. The total upwelling due to the Ekman drift alone

amounts to 4.6 million m³/sec in the coastal zone, and the sinking in the offshore zone amounts to 3.8 million m³/sec. This Ekman flow, however, does not exclusively determine the vertical motion at the bottom of the Ekman layer because the divergences and convergences of the horizontal geostrophic flow within this layer have to be added. It is assumed that this Ekman flow is restricted to a depth of not more than 100 m.

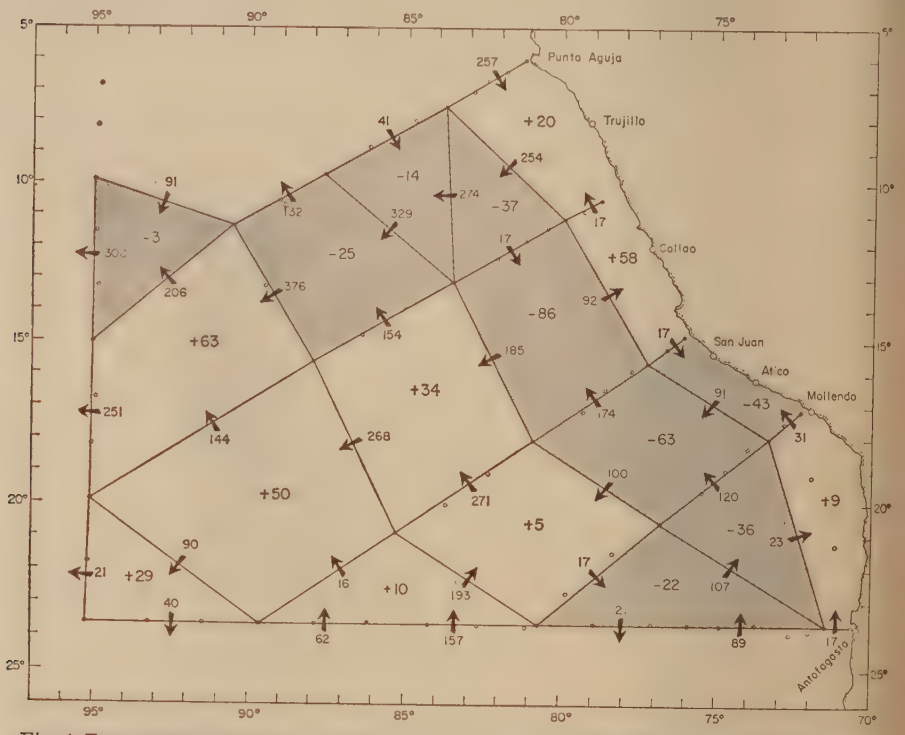


Fig. 4. Transports in the layer between 0–100 m depth in $10^{10}$cm³/sec together with the convergences and divergences (shaded) of this layer. Divergences in this layer are equivalent to upward transport across the 100-m level; convergences, to downward transport.

The combined transports of geostrophic flow and Ekman flow in the layer 0–100 m are shown in figure 4. About equal amounts of 2.6 million m³/sec enter the region from north and south, and 5.7 million m³/sec leave the region to the west. The convergences and divergences of this flow, which are equivalent to the transports across the 100-m level, show that the area of ascending motion is shifted away from the coastline (compare figs. 2 and 4) and that weak descending motions occur along the coast in the 100-m level. This demonstrates that the coastal upwelling is restricted to depths of less than 100 m. This finding is very much in accordance with the estimate of a minimum depth of the coastal upwelling of 67 m obtained by Gunther (1936) from the examination of temperature sections. The high opposite values of the transports across 100 m in the two areas off Callao and off Atico seem to be caused by a disturbance of the hydrographic structure by a gale when the

stations off San Juan were occupied. Treating the two areas together, the downward flow across 100 m depth would only be 0.15 million $m^3$/sec. This result demonstrates that the divergence of the Ekman flow in the coastal upwelling area is compensated by a highly convergent geostrophic flow which has an onshore component and takes its water from ascending motions farther offshore. Altogether the total upward flow across the 100-m level in the whole region amounts to

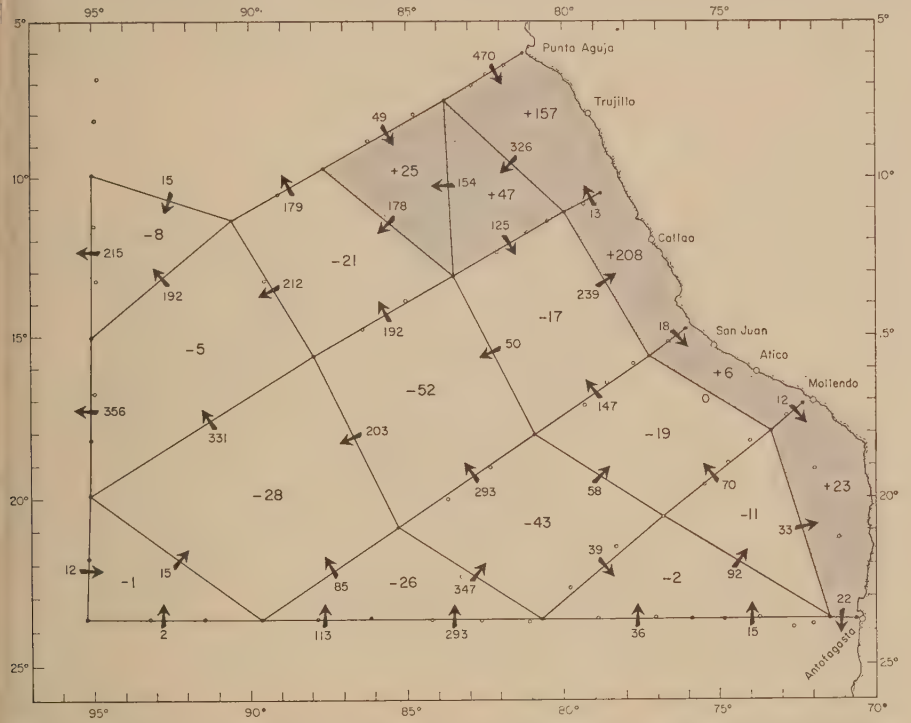


Fig. 5. Transports in the layer between 100 m and 300 m depth in $10^{10}$cm$^3$/sec together with the convergences (shaded) and divergences of this layer.

3.3 million $m^3$/sec and the total downward flow to 2.8 million $m^3$/sec, giving a surplus of 0.5 million $m^3$/sec which leaves the region to the west. These transports are smaller than the transports caused by the Ekman flow because of the convergence of the geostrophic flow.

The transports in the layer between 100 m and 300 m depth (fig. 5) are highly convergent. Some 3.5 million $m^3$/sec enter the region from the north and 4.4 million $m^3$/sec from the south, but only 5.6 million $m^3$/sec leave to the west, causing a convergence of 2.3 million $m^3$/sec. This convergence is concentrated along the coast and especially in the north of the region. It amounts to a total of 4.4 million $m^3$/sec, whereas the divergence in the offshore region amounts to only 2.1 million $m^3$/ sec. The area with the strong convergence coincides with the part of the region where the flow is predominantly southward. In its extent and position it agrees with the Peru-Chile Undercurrent described by Wooster and Gilmartin (1961).

This south-flowing current is highly convergent and seems to supply most of the upwelling water coming from the north as well as the water descending in deeper layers. The divergence in the offshore region coincides with the Peru Oceanic Current where the flow turns gradually from a northerly into a westerly direction.

In the layer between 300 m and 700 m depth (fig. 6) the horizontal flow is considerably weaker than in the layers above it. The pattern of the circulation is still the same, however. There is an inflow into the region from the north (0.7 million

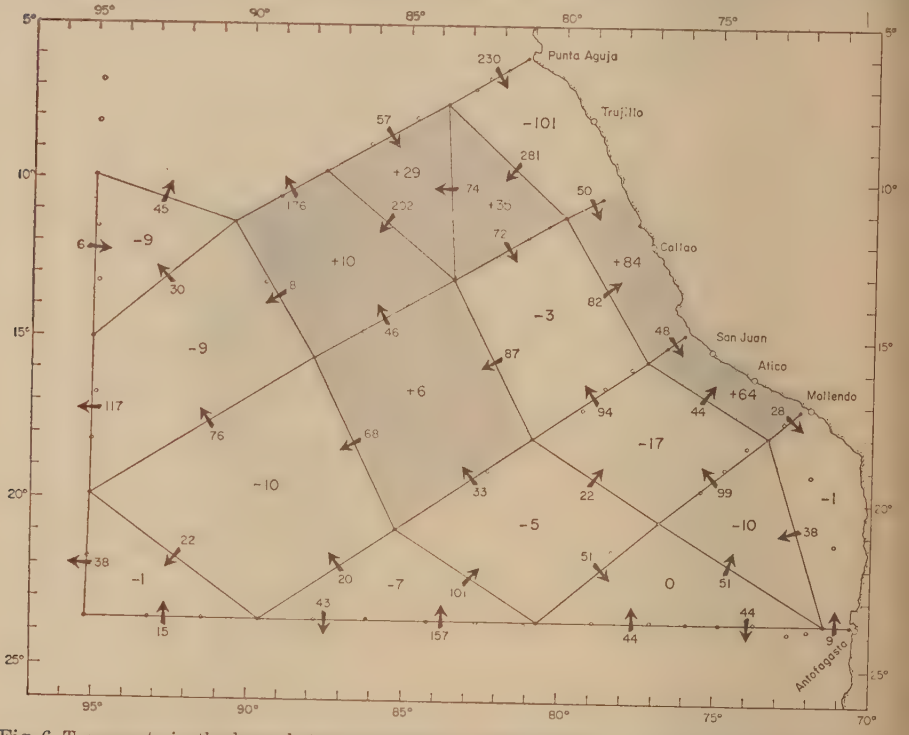


Fig. 6. Transports in the layer between 300 m and 700 m depth in $10^{10}$cm$^3$/sec together with the convergences (shaded) and divergences of this layer.

m$^3$/sec) and from the south (1.4 million m$^3$/sec), and an outflow of 1.5 million m$^3$/sec to the west. The convergences associated with this flow are chiefly situated along the coast and in the north of the region, while weak divergences are found in the south and west. Along the coast the flow is to the south and indicates that the Peru-Chile Undercurrent extends to depths of about 600–700 m, at least in the area north of 20° S. Although the strongest flow seems to occur near 200 m depth, the distribution of salinity and oxygen in a section parallel to the coast, as shown by Wooster and Gilmartin (1961: figs. 10 and 11), indicates that, in the area north of 20° S., water with characteristics similar to that of the Undercurrent extends to about 700 m depth. Near 25° S. a sharp horizontal discontinuity in salinity and oxygen content in depths between 500 m and 900 m marks the southern boundary of that spreading. South of this boundary the Antarctic Intermediate Water is

found in these depths. The flow to the south along the coast shows convergences where it has an onshore component, and divergences where an offshore component is found. In the open ocean, away from the boundary, convergences are associated with poleward flow and divergences with equatorward flow in accordance with the variation of the Coriolis parameter.

The flow in the layer between 700 m and 1,400 m depth is generally weak and the flow pattern has changed (fig. 7). There is an inflow of 0.7 million m³/sec

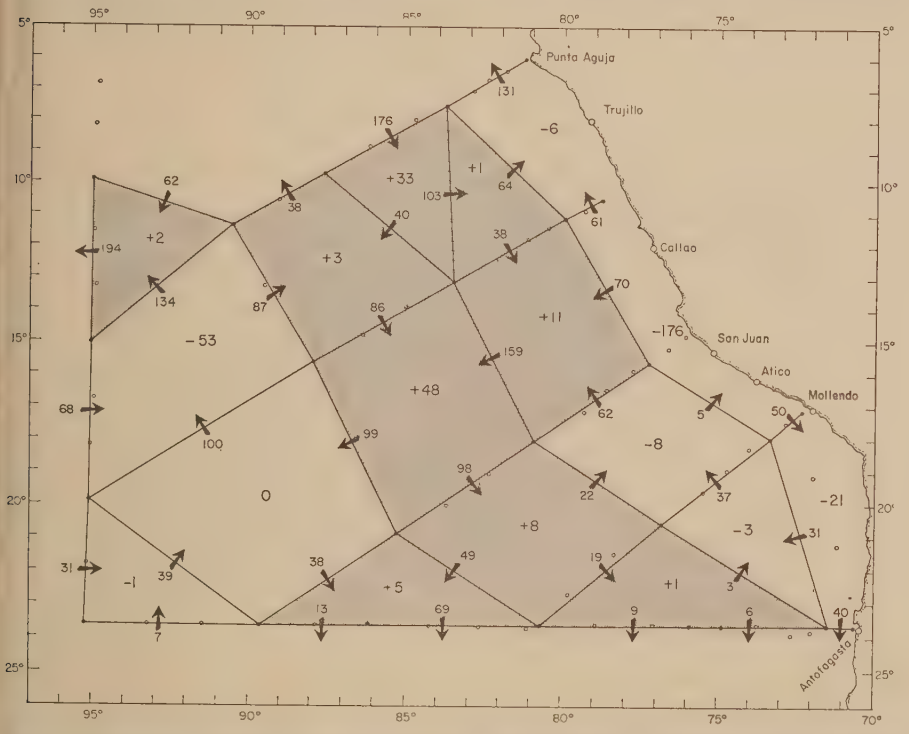


Fig. 7. Transports in the layer between 700 m and 1,400 m depth in $10^{10}$cm³/sec together with the convergences (shaded) and divergences of this layer.

from the north, but outflow occurs to the west (1.0 million m³/sec) and to the south (1.3 million m³/sec). There is an excess of outflow of 1.6 million m³/sec in this layer, and the associated divergences are situated chiefly along the coast. In this layer most of the downward flow, caused by the convergence of the Undercurrent, is absorbed and carried out of the region.

The flow in the deep layer between 1,400 m and 3,000 m depth is again strong and the flow pattern has changed completely (fig. 8). An inflow of 3.1 million m³/sec into the region takes place from the west. This water turns south, and 3.5 million m³/sec leave the region to the south. There is also a weak outflow of 0.4 million m³/sec to the north, so that the layer as a whole is divergent. Divergences occur where the flow is equatorward, and convergences where the flow is poleward. The strong divergence along the coast off Callao and Atico is compensated im-

mediately offshore where the deep flow to the east makes a sharp turn to the south. This flow transports 5–7 million m³/sec and is comparable in strength to the surface circulation. Its velocities are much smaller because it is spread over a depth interval of 1,600 m. The inflow into the region from the west occurs between 10° S. and 20° S. and carries 5 million m³/sec. The current flows almost due east and its transport increases to 6 million m³/sec when it crosses 85° W. Then it turns

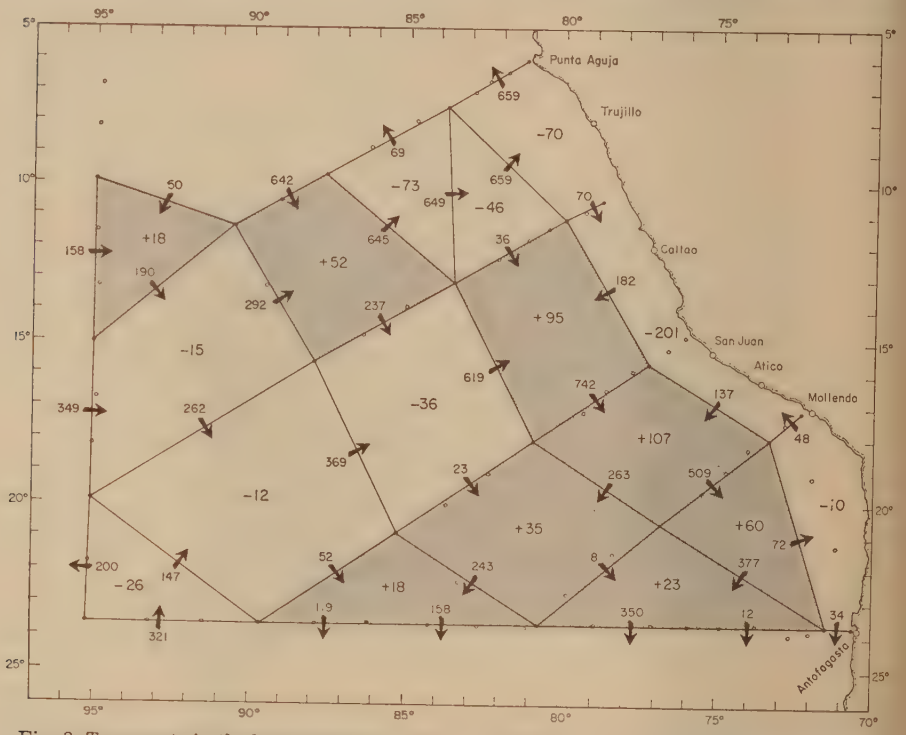


Fig. 8. Transports in the layer between 1,400 m and 3,000 m depth in $10^{10}$cm³/sec together with the convergences (shaded) and divergences of this layer. Convergences in this layer are equivalent to ascending flow across the 1,400-m level; divergences, to descending flow.

sharply to the south and the transport increases to 7.5 million m³/sec when it crosses 19° S. South of this position the current widens and 6.3 million m³/sec leave the region between 75° W. and 90° W. in a southerly direction.

Because it had been assumed that the vertical velocity at 3,000 m depth vanishes, the convergences and divergences of this layer represent also the flow across the 1,400-m level. The upward flow of 4.1 million m³/sec in some parts of the region is opposed by a downward flow of 4.9 million m³/sec in other parts of the region, resulting in a total divergence of this layer of only 0.8 million m³/sec. It is worth mentioning that the vertical motions on the top of this deep layer are of the same order as the horizontal motions. But when they are averaged over a larger area, the contributions of upward and downward motion cancel, and the vertical transports in these depths are one order of magnitude smaller than the horizontal

transports. This means that actual vertical velocities in these depths will be more than ten times greater than the average vertical motion, integrated over a larger area. These fluctuations are of the same order as those of deep currents, where individual measurements exceed the average velocity usually by one order of magnitude. Therefore it seems impractical to measure the average vertical motion in the deep layers of the ocean, even if apparatus could be designed to measure the actual vertical motion in these depths.

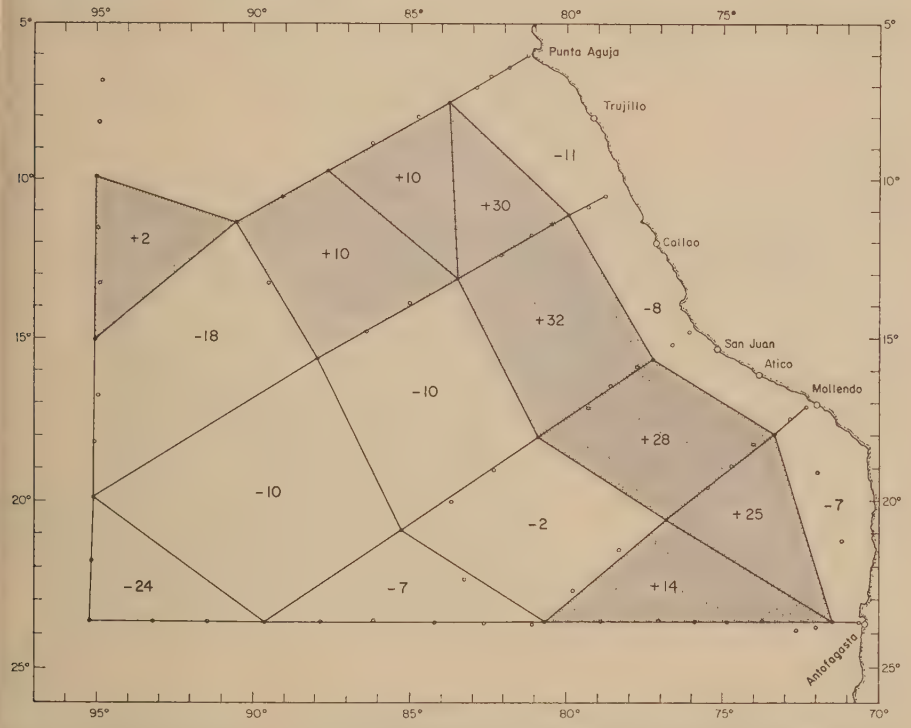


Fig. 9. Vertical velocity at 100 m depth in $10^{-5}$cm/sec (+, ascending (shaded); −, descending).

## THE VERTICAL FLOW

The vertical velocities at 100 m depth, as calculated from the divergence of the flow in the layer between the surface and 100 m, are shown in figure 9; their range is 5–30 $10^{-5}$cm/sec. Along the coast descending movements are indicated with a velocity of about 2 m/month. This shows that the ascending motion due to the divergence of the Ekman layer is concentrated in depths of less than 100 m. An inspection of the temperature section of Step-I Expedition shows that near the coast the isotherms are bent upward only above approximately 100 m and are curved downward below that depth. Thus, the neutral point between ascending and descending motion along the coast is slightly above 100 m depth and the coastal upwelling is a comparatively shallow process. There seems to be no doubt that during periods with winds much stronger than average, the upwelling will

extend to somewhat greater depths, but such a situation will have to be treated with a time-dependent wind stress, and accelerations must be considered.

Farther offshore the vertical motions across 100 m are upward, with velocities of about 7 m/month. As the horizontal motion in these depths below the Ekman layer is in general onshore, water in the range of the discontinuity layer is transported onshore and upward, thus supplying the upwelling along the coast. In sections perpendicular to the coast the isotherms within the discontinuity layer rise

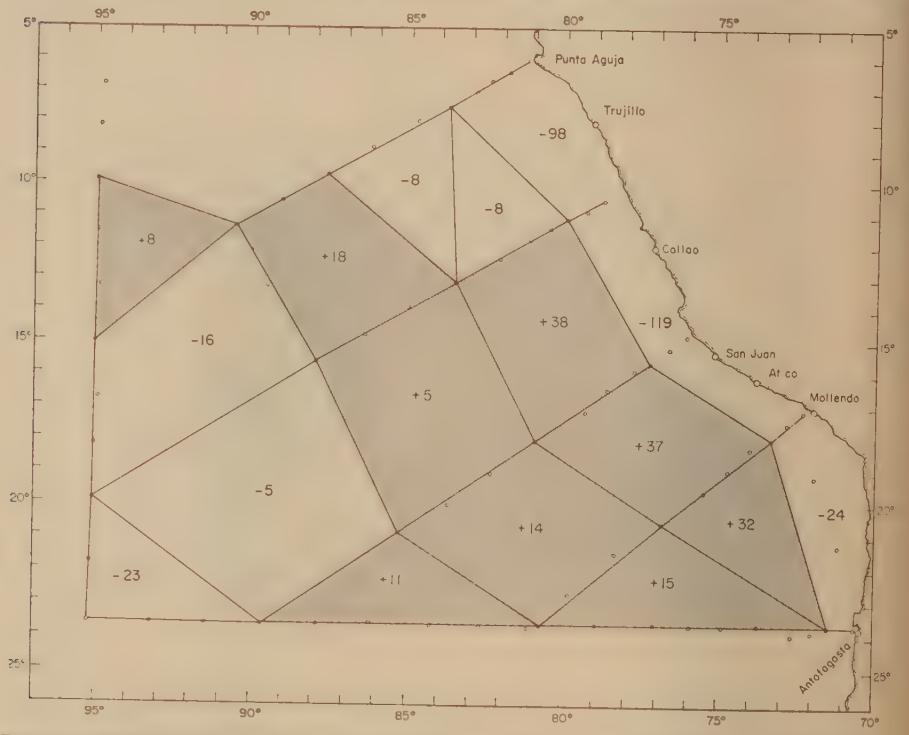


Fig. 10. Vertical velocity at 300 m depth in $10^{-5}$cm/sec (+, ascending (shaded); −, descending).

by about 50 m within 500 km when approaching the coast. Taking an ascending motion of 30 $10^{-5}$cm/sec, an onshore flow of 3 cm/sec would be necessary to maintain a temperature distribution in equilibrium if mixing could be neglected in a first approximation. This estimated velocity seems to be quite reasonable and shows that onshore flow together with ascending motion in the offshore region supply the upwelling along the coast, and that these ascending motions are found progressively deeper at greater distances from the coast. It must be mentioned, however, that these movements are superimposed on the general flow parallel to the coast.

In the southwest of the region water is descending with velocities of about 2–3 m/month, chiefly as a result of the convergence of the Ekman flow. Another feature worth mentioning is the extension of the area with ascending motion to-

ward the northwest away from the coast. This area probably extends toward the equator and leads over into the equatorial upwelling as predicted theoretically by Yoshida (1963). Unfortunately, the network of stations of the Step-I Expedition does not allow the calculations to be extended into this area. This extension of the upwelling area from the coast off Peru toward the northwest to the equator will probably provide a better explanation of the low surface temperatures observed in this area than will advection.

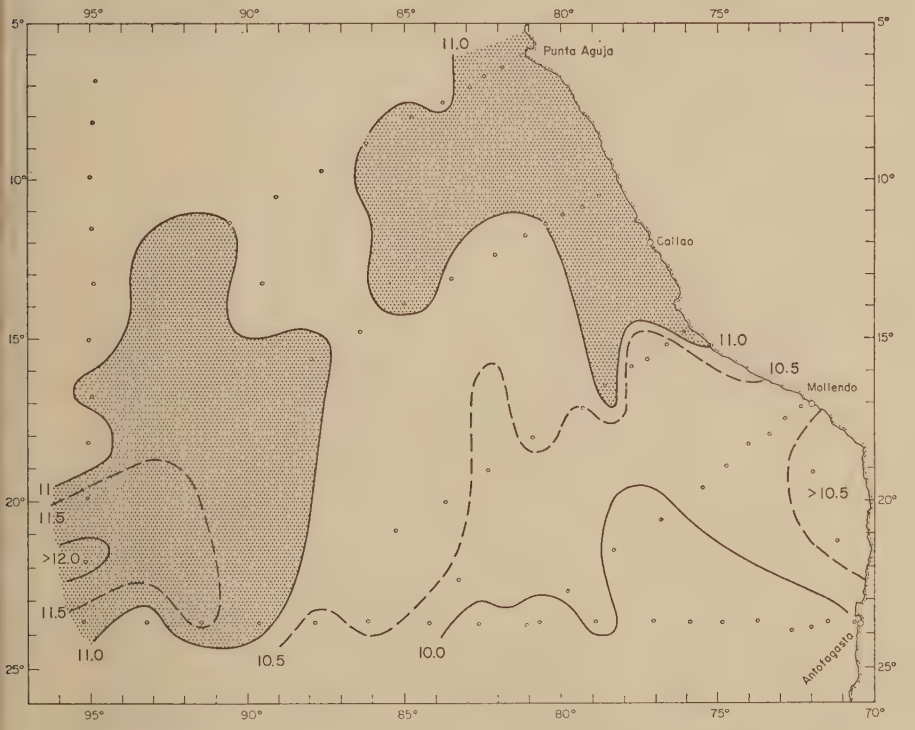


**Fig. 11. Distribution of temperature at 300 m depth. Areas with a temperature above 11° C. shaded.**

In 300 m depth the descending velocities along the coast have increased to values of 30 m/month in the area off Callao and Atico (fig. 10). These high values, as well as those in deeper layers, seem to result from a disturbance of the hydrographic situation by a gale at the time when the stations off San Juan were worked. Therefore only the average value for the two areas is given. The offshore area with ascending motions extends farther to the west than in 100 m depth and beyond the line where the Ekman flow near the surface is divergent. This shows that the field of vertical motions connected with the upwelling at the surface along the coast is of a considerable extent and influences the whole structure of the ocean and the connected field of motion far away from the coast. The extent of this ascending motion is further evidence for the conclusion drawn above: that the ascending motion extends to deeper levels with increasing distance from the coast.

The distribution of vertical velocity at 300 m should, to a certain extent, be reflected in the distribution of properties in this depth, especially in that of temperature and density. A comparison of the vertical velocity (fig. 10) with that of the temperature in 300 m depth (fig. 11) demonstrates these relations. The area of strong descending motion along the coast and in the north of the region coincides with a positive temperature anomaly. A negative temperature anomaly is found in the area with ascending movements farther offshore. The area with descending movements in the southwest is again reflected by higher temperatures. This agreement does not seem to be incidental, but can be taken as a confirmation of the distribution of vertical motion as calculated.

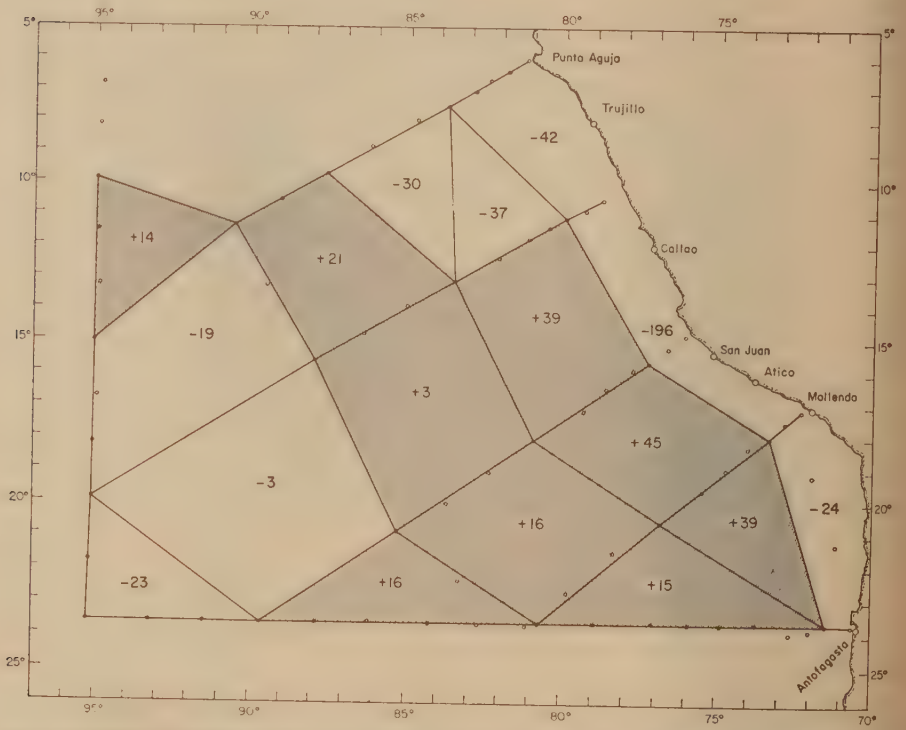


Fig. 12. Vertical velocity at 700 m depth in $10^{-5}$cm/sec (+, ascending (shaded); −, descending).

The distribution of vertical velocity in 700 m depth (fig. 12) resembles very closely that in 300 m, indicating that the divergence of the horizontal flow between 300 m and 700 m is weak. Movements are downward along the coast and in the north, and upward in the offshore area. Only at distances of more than 1,000 km from the coast in the range of the Peru Oceanic Current is the motion downward again.

A very similar distribution of vertical velocity is also found in 1,400 m depth (fig. 13). The vertical movements across this surface reflect, however, the di-

vergences and convergences of the deep flow below 1,400 m. The motion is ascending where the deep current flows poleward and descending where it flows equatorward. Only along the coast do strong descending movements occur, and the water masses, forced down from higher levels, are integrated into the horizontal flow.

## THE THREE-DIMENSIONAL FIELD OF MOTION

The purpose of this investigation is chiefly to study the relation of the upwelling along the coast to the general circulation in the whole region. Therefore it is necessary to investigate the combined effects of horizontal and vertical motion and to

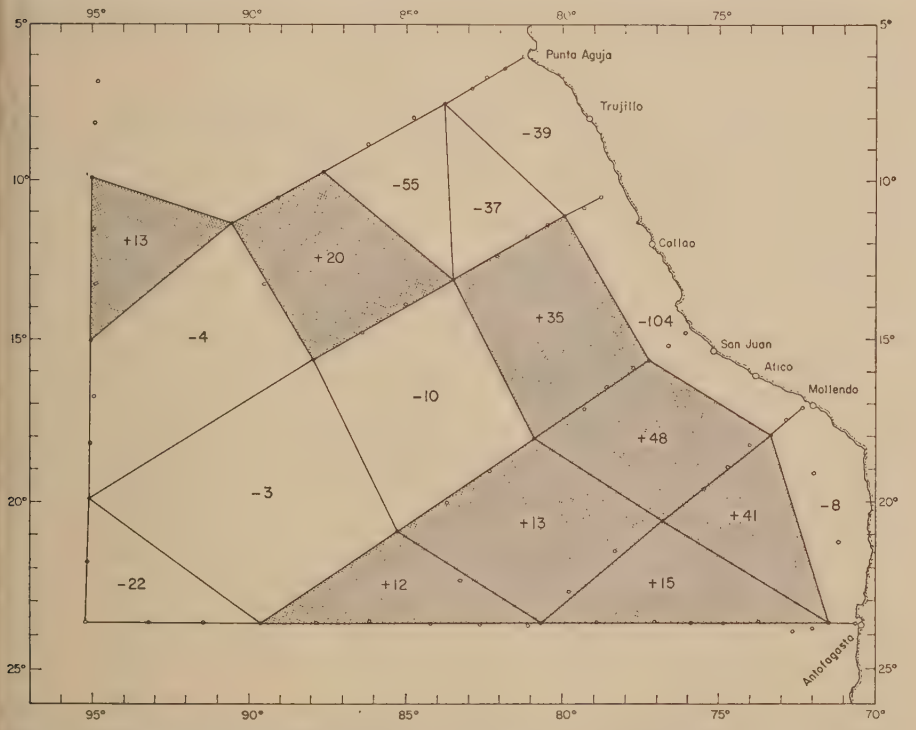


**Fig. 13. Vertical velocity at 1,400 m depth in $10^{-5}$cm/sec (+, ascending (shaded); −, descending).**

compare them with the distribution of properties of the water masses in order to arrive at conclusions about the sources of the upwelling water. To illustrate the three-dimensional flow pattern a schematic block-diagram is shown in figure 14 for the entire region studied. The horizontal transports across its three sides are given for different depth intervals together with the vertical transports across these levels. In the surface layer, inflow into the region is from north and south, and outflow to the west. This outflow exceeds the inflow, so that ascending movements occur at the bottom of this layer. The resulting ascending transport is only small because the region comprises an area of upwelling as well as an area of sinking

(fig. 4). The same flow pattern is found in the layer between 100 m and 300 m depth, but here the inflow exceeds the outflow considerably, so that the layer is highly convergent. The inflow from the south is almost completely deflected to the west, and only small parts of it get underneath the upwelling area and contribute to upwelling (fig. 5). The inflow from the north causes a strong convergence of the horizontal flow along the coast and in the north of the region. This convergence supplies the ascending motion on the top of the layer as well as the descending motion on its bottom. This subsurface layer of strong convergence of the horizontal flow provides the potential for the upwelling even if the winds are the driving forces of this process. Thus, with winds stronger than average, most of the convergent subsurface flow will turn into upwelling, whereas during periods of weak winds this convergence will cause descending motion in subsurface layers along the coast.

Between 300 m and 700 m depth the motion is considerably weaker but still convergent. The maximum of the downward motion occurs in about 700 m depth, thus separating the layer of the upper circulation from the deep circulation. Below this depth the flow is divergent, thus absorbing the water descending from the upper layer. Water enters the region chiefly from the west and leaves to the south.

Because the region under consideration comprises an area of upwelling and an area of sinking, the presentation of the flow given in figure 14 is not quite satisfactory and therefore the upwelling area will be treated separately to outline the water movements engaged in this process. For this presentation the upwelling area is considered to be determined by the coast in the east and by the position of the maximum wind stress in the west. This line lies about 500–800 km offshore. Figure 15 shows the vertical distribution of inflow and outflow across the three sides of the area and the average distribution of vertical velocity. First the difference between a very strong inflow from the north and a very weak inflow from the south can be noted. The outflow in the upper layer takes place to the west, and about half of it is concentrated in the Ekman layer. The distribution of vertical velocity shows that the upwelling has an average thickness of about 200 m, which results from the fact that the ascending motion farther offshore occupies a much thicker layer than the coastal upwelling. This coastal upwelling was shown to extend to a depth of not more than 100 m under average wind conditions. Below 200 m depth, descending motion is found. The horizontal flow in the layer between 100 m and 700 m is highly convergent, thus supplying the upwelling on top and the sinking on the bottom of this layer. Below 700 m the horizontal flow is divergent, thus absorbing the descending water. Below 1,400 m depth the deep water enters the region from the west and leaves it to the north and to the south. It is worth mentioning that the total transport across the southern section, integrated from the surface to the bottom, is to the south. This agrees with the sign of the wind stress curl in this area which requires Sverdrup transports to the south.

The distribution of vertical velocity, which was calculated for all individual quadrangles, shows some characteristic trends in different areas; its distribution in five areas is represented in figure 16. The area to the west of Iquique shows ascending motions in the whole water column due to southward flow in the deep

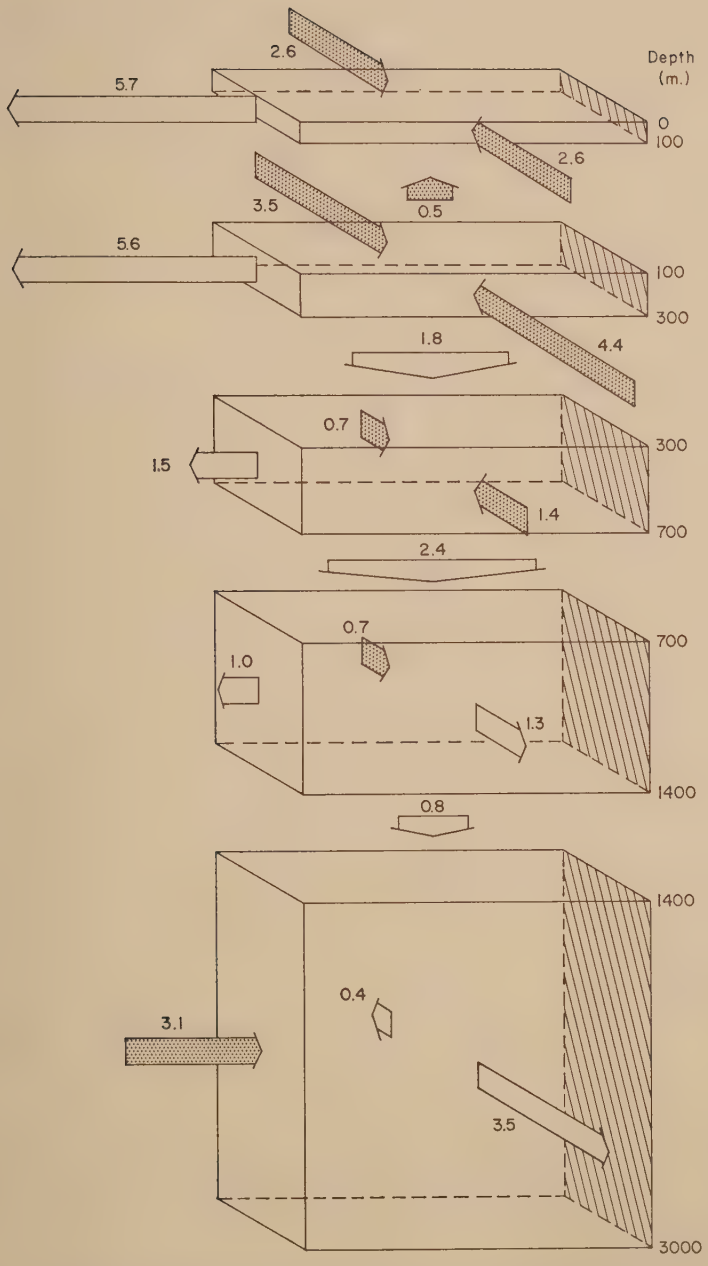


Fig. 14. Block-diagram of the water balance in different layers off the coast of Peru in million $m^3$/sec, giving horizontal transports in five layers and vertical flow between these layers.

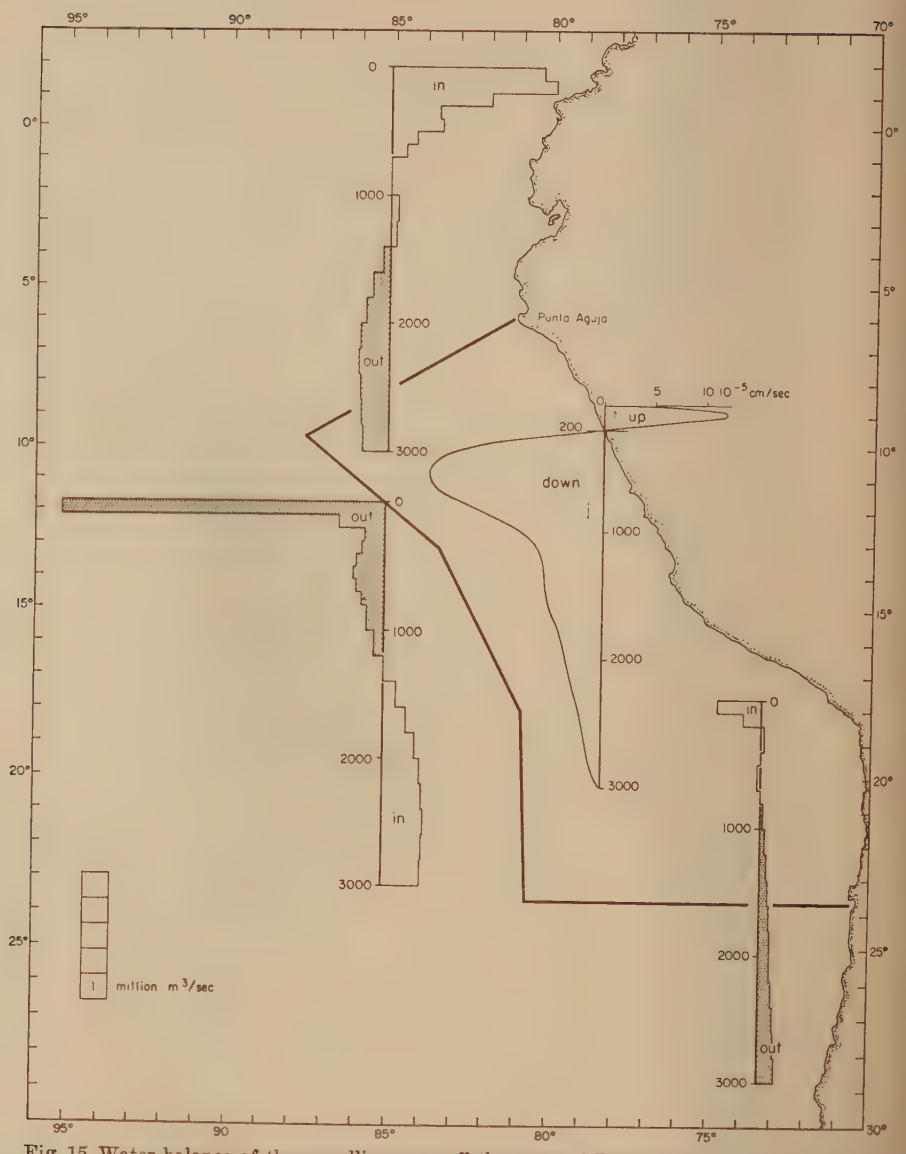


Fig. 15. Water balance of the upwelling area off the coast of Peru showing the vertical distribution of the horizontal flow across the northern, western, and southern boundaries of the area and the average vertical velocities. Each square of the scale in the lower left of the figure represents a flow of 1 million $m^3$/sec.

layer and to northward flow near the surface. In the central part of the region, off Below this depth descending motions of the same order of magnitude are found. Callao and Atico, the upwelling is strongest and restricted to the upper 250 m. Below 1,500 m vertical movements are weak. A comparison of this distribution

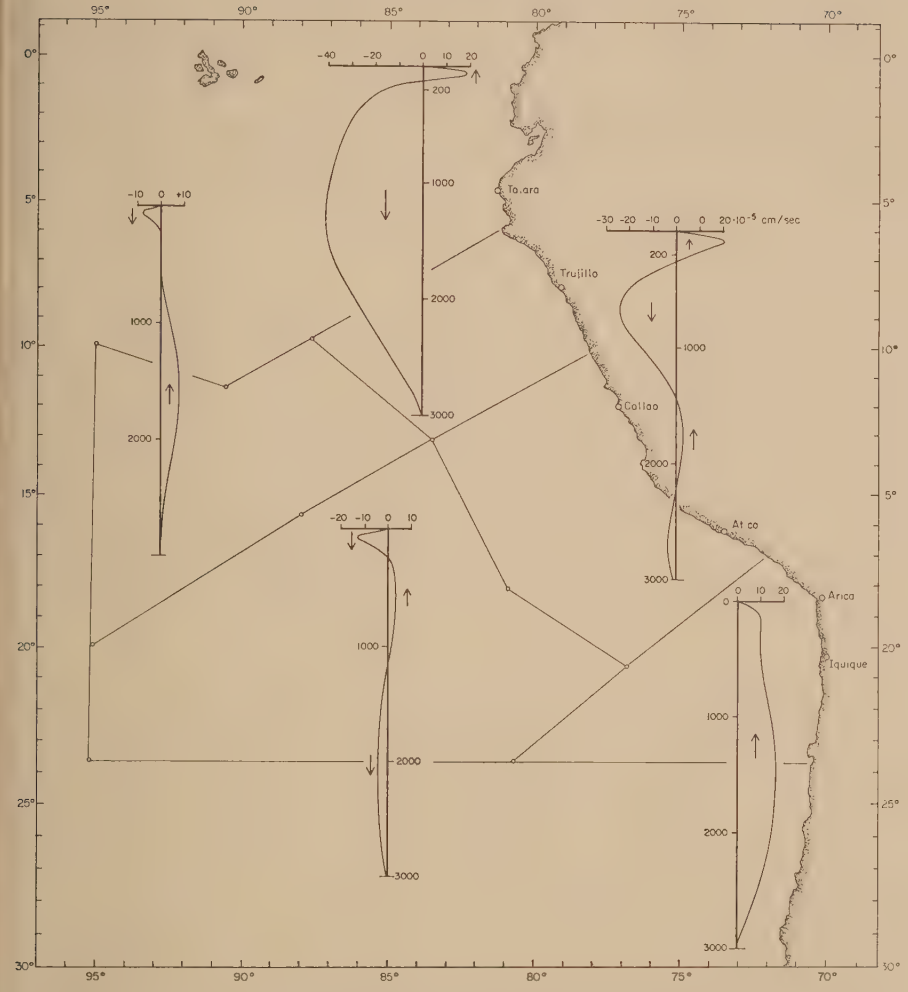


**Fig. 16. Vertical distribution of vertical velocity in five selected areas off the coast of Peru between the surface and 3,000 m depth in $10^{-5}$cm/sec.**

with the vertical velocities in the individual quadrangles, as given in figures 9, 10, 12, and 13, shows that averaging over the four quadrangles eliminates all the high vertical velocities. These are probably the result of a disturbance of the hydrographic situation by a gale when the stations off San Juan were occupied, as mentioned above. In the northern part, off Trujillo, the upwelling is restricted to much shallower depths, and underneath, strong descending movements are found. These are caused by the deep flow to the north, which is divergent, and by the flow to the south in the upper layer being convergent.

In the two offshore areas the vertical velocities are much smaller than those in

the coastal areas. Between the surface and 200 m descending movements are found, indicating the convergence of the Ekman layer. In the deeper layers weak vertical movements are due to the divergence and convergence of the horizontal flow. This demonstrates that the major contributions of the horizontal circulation to vertical movements take place along the coast.

One additional result of these calculations is that no coherent surface of no horizontal motion was found. The layer of no horizontal motion, $u = v = 0$, should simultaneously be a layer of extreme vertical motion

$$\frac{\partial w}{\partial z} = 0.$$

However, the depths at which the geostrophic velocity perpendicular to a section vanished were usually different at the three sides of each triangle. These depths, together with the depths of extreme values of the vertical velocity, could not be charted in a simple way. There is, however, a layer of very weak horizontal flow near 700 m, or more precisely between 600 m and 1,000 m depth, but this layer is not essentially motionless. In this layer also the strongest vertical motions occur (fig. 14). Moreover, this layer is the boundary between the circulation in the upper layer and the deep circulation which follow essentially different patterns. These results lead to the conclusion that there will be layers of very weak horizontal movements separating the circulations of the upper layer and the deep layer in the oceans, but there will be no surface where the horizontal motion vanishes identically.

## CIRCULATION FEATURES OF SMALLER SCALE

The method used above for the calculation of the horizontal and vertical transports does not resolve circulation features smaller than the distance of the deep stations, and consequently certain features of smaller scale have been suppressed by the use of this method. On the other hand, calculation of the absolute topography of the sea surface has shown that it deviates by less than ±1 cm from the topography relative to 1,000 decibar (fig. 2). Therefore the topographies relative to 1,000 decibar can be used for a discussion of the circulation pattern near the surface without introducing any noticeable bias. The topographies of the sea surface, of the 100-decibar, and of the 200-decibar surfaces relative to 1,000 decibar in figures 17, 18, and 19 are drawn with an isobar spacing of 2 dynamic cm.

West of 82° W. the offshore branch of the Peru Current, or the Peru Oceanic Current as Gunther (1936) termed it, flows north. This current reaches to about 700 m depth, turns to the west, and leaves the region south of 10° S. It has little interaction with the currents farther inshore and is situated completely to the west of the line of maximum wind stress. Between 78° W. and the coast, the Peru Coastal Current enters the region from the south. It loses strength considerably when proceeding to the north, and reaches only to about 10° S., just north of Callao. The movements in this current are to the north and onshore. The convergence of this geostrophic flow along the coast is compensated by the Ekman flow away from the coast. The strength of this current decreases also with depth, and in 200 m it is only weakly developed (fig. 19). In subsurface layers an undercurrent is developed along the coast, as can be seen from the topographies at 100 m and 200 m. This subsurface flow to the south close to the coast is the undercurrent

neasured by Wooster and Gilmartin (1961). This Undercurrent is only weak and ts transports are small; it should be well distinguished from the Countercurrent, liscussed next.

Between the Peru Oceanic Current and the Peru Coastal Current a counter-urrent flows south. Off Talara this countercurrent starts right at the coast and extends about 250 km to sea. At Punta Aguja it leaves the coast and flows almost

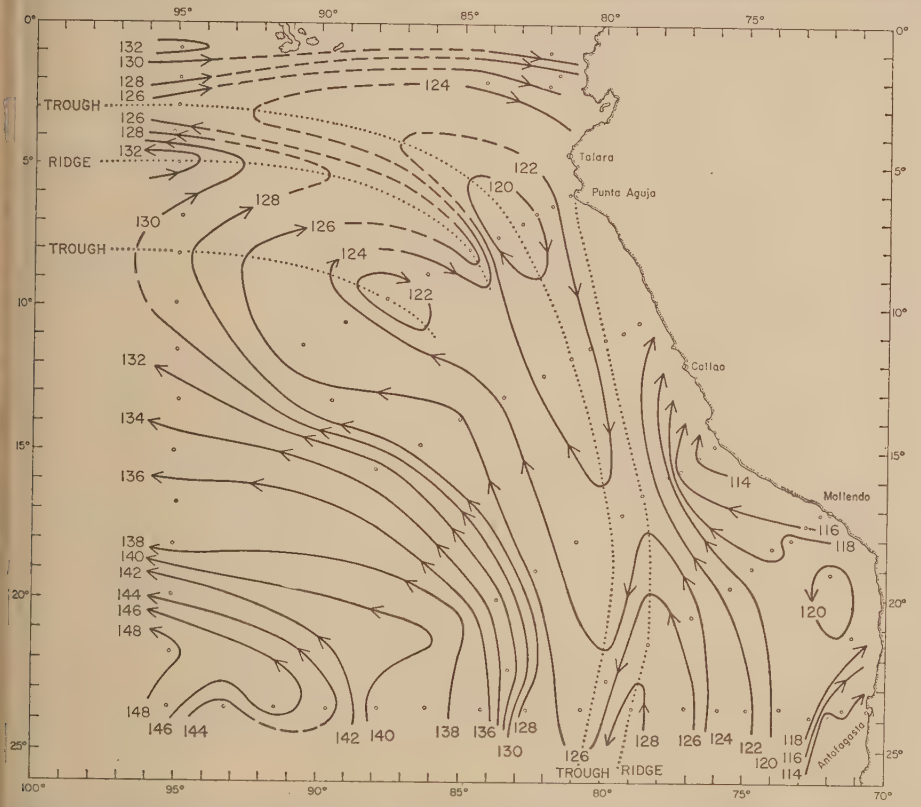


Fig. 17. Geopotential topography of the sea surface relative to the 1,000-decibar surface in dynamic cm. The positions of troughs and ridges are indicated. Broken lines represent extrapolation.

due south. This flow is strongest near 100 m depth but is also shown in the topographies at the surface as well as in the 200 m depth. At the surface the countercurrent may not be noticeable from observations because the superimposed Ekman current will conceal it. Moreover, the isobars at the surface (fig. 17) show that water from the Peru Coastal Current passes through the countercurrent into the Peru Oceanic Current. This countercurrent can clearly be seen in the sections published by Wooster and Gilmartin (1961:figs. 14–18) where geostrophic speeds perpendicular to the five profiles are shown. These profiles demonstrate that the countercurrent is separated from the coastal undercurrent in all sections south of Punta Aguja and that the countercurrent is stronger than the Peru Undercurrent in which the current measurements had been made.

Ridges and troughs in the topography of the various surfaces are connected with this current system. A trough is situated on the right-hand side of the Peru Oceanic Current and a ridge on the left-hand side of the Peru Coastal Current. Between this ridge and this trough the Peru Countercurrent flows south. Another trough develops along the coast separating the northward-flowing Peru Coastal Current from the southward-flowing coastal Undercurrent. This trough can be

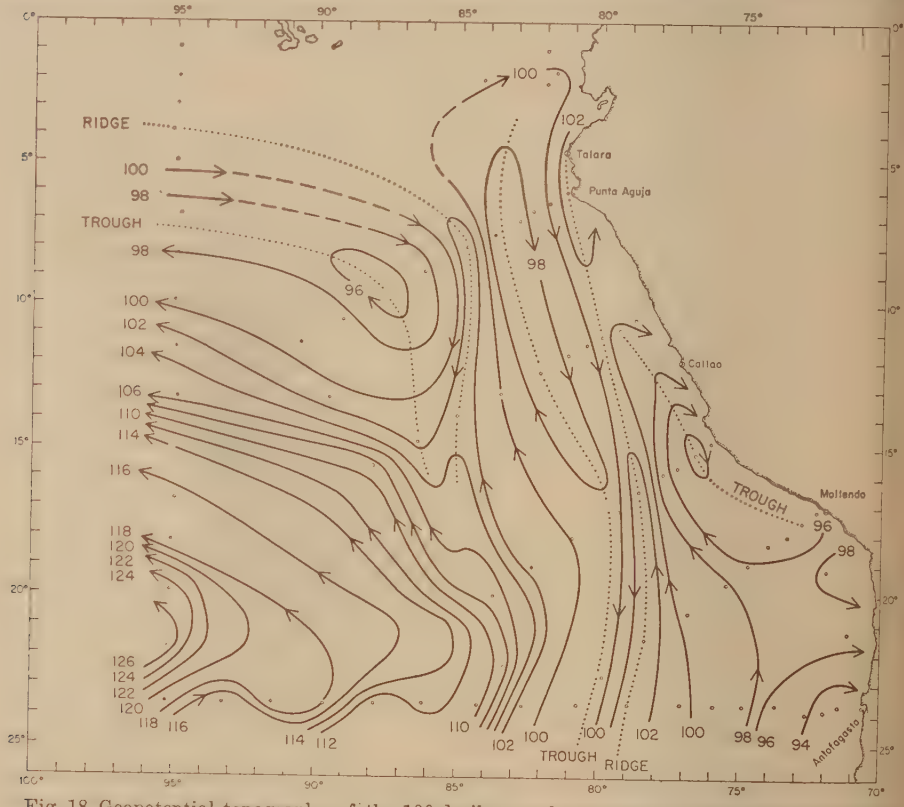


Fig. 18. Geopotential topography of the 100-decibar surface relative to the 1,000-decibar surface in dynamic cm. The positions of troughs and ridges are indicated. Broken lines represent extrapolation.

seen at 100 m and 200 m depth (figs. 18 and 19) but is not shown in the topography of the sea surface, indicating that this current is a real undercurrent. It is probably related to the strong descending motion underneath the thin upwelling layer along the coast.

The Countercurrent is probably a direct consequence of the deviation of the Peru Oceanic Current away from the coast to the northwest. If the sea level in the trough along its right flank is lower than the sea level along the ridge to the left of the Peru Coastal Current, this situation must result in a geostrophic flow to the south between the ridge and the trough—the Countercurrent. This current transports water of equatorial origin south and will probably be subject to considerable

variations, seasonally as well as from year to year. It is likely that its fluctuations are responsible for the occurrence of El Niño.

In the northwestern part of the region, north of about 10° S., the topography of the sea surface cannot be drawn with confidence, but some of the features indicated are worth mentioning. When the Peru Oceanic Current has turned completely away from the coast between 90° W. and 95° W. and passes over into the

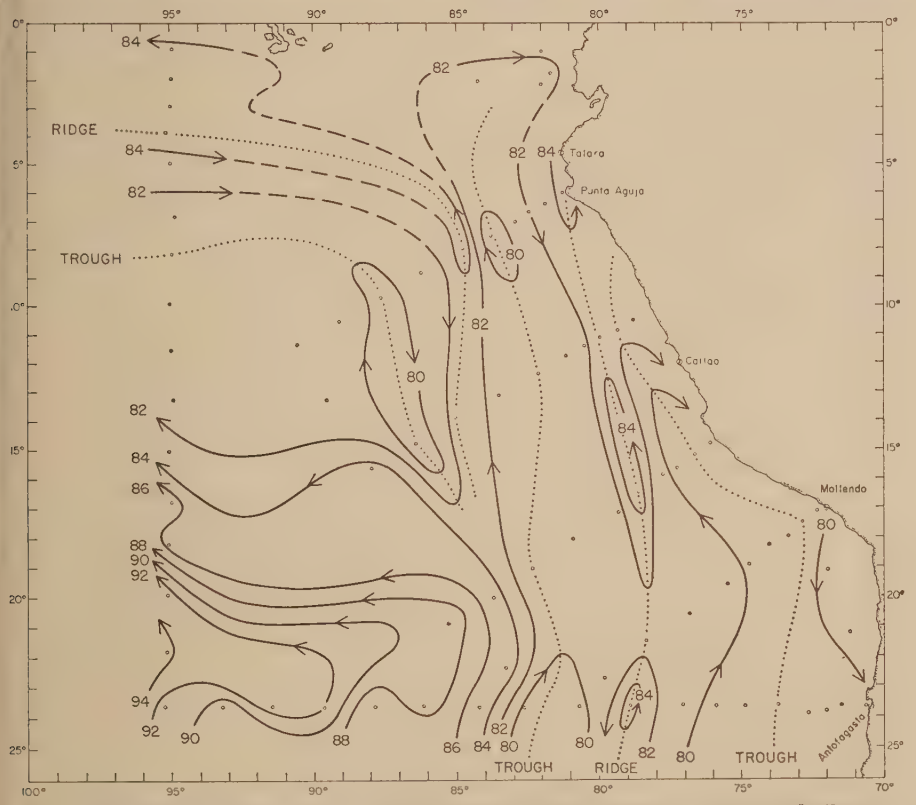


Fig. 19. Geopotential topography of the 200-decibar surface relative to the 1,000-decibar surface in dynamic cm. The positions of troughs and ridges are indicated. Broken lines represent extrapolation.

South Equatorial Current, another countercurrent appears along its northern flank. This is the South Equatorial Countercurrent discussed by Reid (1959) and Wooster (1961). It flows in this region between the trough at about 8° S., which forms the northern boundary of the Peru Oceanic Current, and a ridge near 5° S. The topography of the sea surface shows that this countercurrent merely deflects water of the Peru Oceanic Current into another current flowing west which is situated between 5° S. and 3° S. Because the wind drift in this area is to the southwest, this current is probably not observable at the surface. In subsurface layers, at 100 m and 200 m depths (figs. 18 and 19), the countercurrent does not follow this pattern but is a straight flow between 7° S. and 4° S. Between 88° W.

and 85° W. it turns sharply to the south, proceeds as far as 15° S., and turns west into the Peru Oceanic Current. The effect of this current on the distribution of properties in these layers is worth studying.

Between 3° S. and the equator a strong flow to the east is indicated in the topography of the sea surface, but in 100 m and 200 m depth flow seems to be almost negligible.

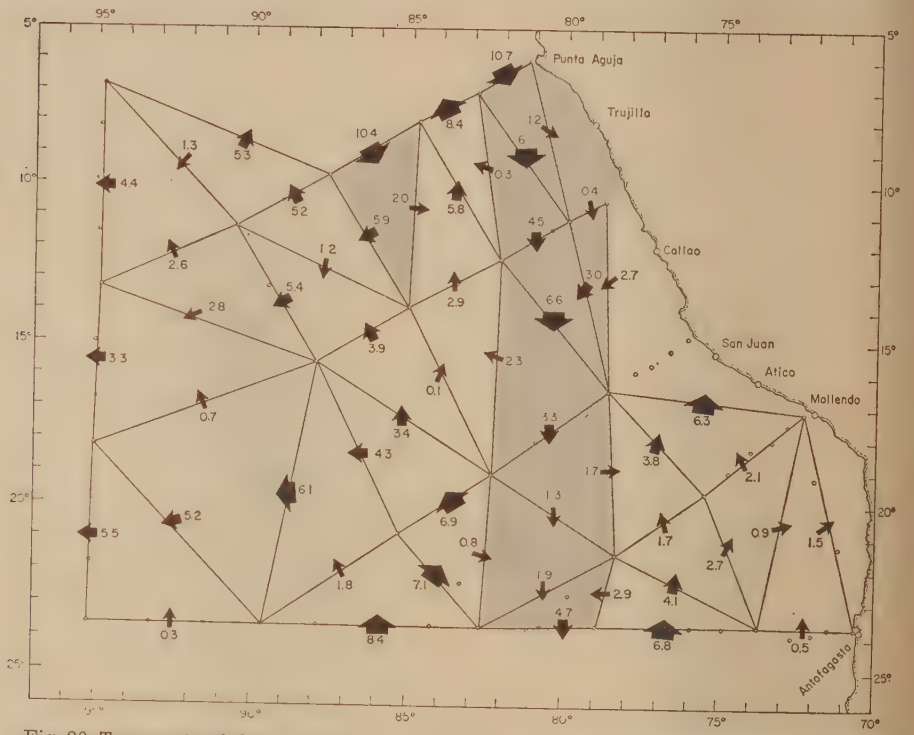


Fig. 20. Transports of the circulation in the upper layer off Peru. These are calculated between the surface and 700 m depth according to the absolute topography and are given in million m³/sec. Flow to the south is shaded (geostrophic transports only).

The transports of the various currents in this region between the surface and 700 m depth across sections formed by pairs of hydrographic stations are shown in figure 20. A station network different from that of 3,000-m stations used for the calculations in the section on Horizontal Flow has been selected, with stations located on each side of the major currents. The absolute topographies of the sea surface at all these stations were determined using the absolute topography of the 1,000-decibar surface shown in figure 3. From these data the absolute geostrophic transports between the sea surface and 700 m depth were calculated and are shown in figure 20. The depth of 700 m was chosen because it was previously found to represent the lower boundary of the circulation in the upper layer.

The Peru Oceanic Current transports about 8 million m³/sec. It gains some water from the South Equatorial Countercurrent. The Peru Coastal Current trans-

ports about 6 million $m^3$/sec to the north which partly supplies the upwelling as well as the sinking along the coast and partly turns back with the Countercurrent. It is not possible to estimate the flow of the Undercurrent along the coast by this method, but figures 5 and 6 show that it amounts to about 0.5–1.0 million $m^3$/sec. The Countercurrent transports 11 million $m^3$/sec off Punta Aguja. This flow decreases rapidly to 6 million $m^3$/sec at 15° S. and to 2 million $m^3$/sec at 22° S. The higher transport farther south seems to be the effect of an eddy at 24° S., 79° W. The South Equatorial Countercurrent enters the station network at about 9° S., 86° W., transporting 10 million $m^3$/sec. Part of this water turns into the Peru Oceanic Current and part of it flows back to the north between the South Equatorial Countercurrent and the Peru Countercurrent. These two separate currents have been combined by Wooster and Gilmartin (1961) to give an estimate of 21 million $m^3$/sec for the southward flow off Punta Aguja. This analysis shows that they are well distinguished currents.

It must be mentioned that the sum of these geostrophic transports across the sides of the various triangles does not usually vanish, because of the vertical flow across the 700-m level and because the divergences and convergences of the Ekman flow are not included. Only the geostrophic parts of the circulation are given.

## THE DISTRIBUTION OF WATER MASSES IN RELATION TO THE CIRCULATION

Because an analysis of water masses in this region will be given in another paper, only a few important relations between circulation and the distribution of water masses will be discussed here. For this purpose the TS (temperature–salinity) curves at six stations situated in the different currents are shown in figure 21 and the positions of the stations are given in figure 22. In depths between 600 m and 900 m, Antarctic Intermediate Water, which is characterized by a salinity minimum, is found in the entire region having temperatures of 5°–6° C. and salinities of 34.3–34.6 ‰. Above the Antarctic Intermediate Water four water masses—two surface and two subsurface—are engaged in the circulation in this region.

At the surface, Subtropical Surface Water of high salinity ($> 35.0$ ‰) and temperatures between 17° C. and 20° C. covers most of the region (fig. 23). It is found in the range of the Peru Oceanic Current (station 63) and in the southern part of the Peru Countercurrent (station 33). This water originates in the subtropical region of the South Pacific Ocean and is brought by circulation into the region off Peru, although evaporation seems to be responsible for maintaining or even increasing its high salinity.

In the northern part of the region, Equatorial Surface Water of low salinity and high temperature is present, as indicated by the TS curve of station 78 in the South Equatorial Countercurrent. This water is usually found north of a front situated at or just south of the equator and covers most of the eastern tropical Pacific (fig. 23). Near the equator the layer of this water is very shallow, mostly less than 30 m thick.

Below this shallow surface layer, water of higher salinity ($> 35.0$ ‰) is found everywhere in the northern part of the region. This water is a mixture of Sub-

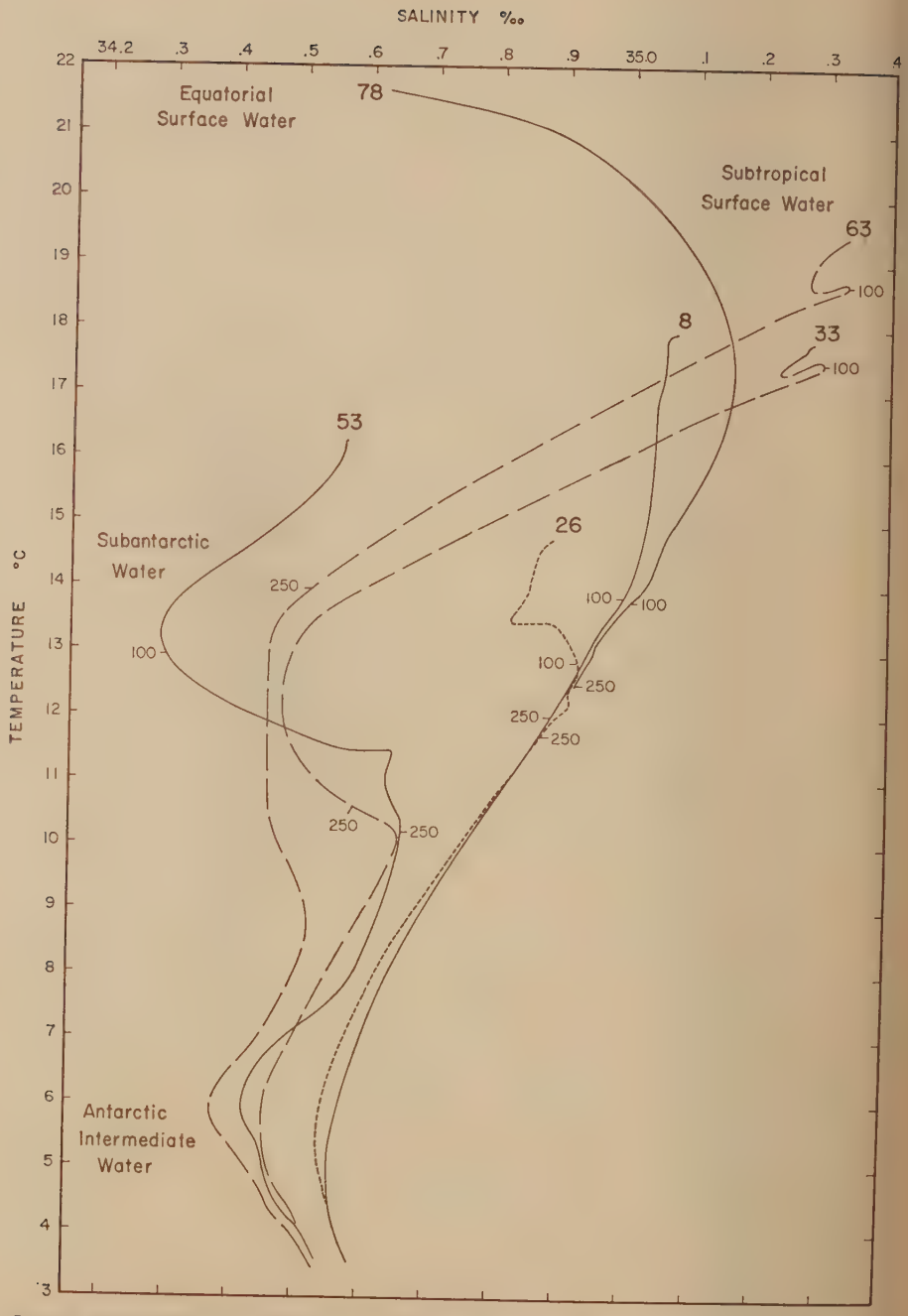


Fig. 21. Temperature–salinity diagrams of six stations off Peru, demonstrating the hydrographic structure. Small figures indicate depth along the TS curves. Heavy figures at the head of the curves are station numbers (the station positions are shown in fig. 22).

tropical Surface Water and Antarctic Intermediate Water, and is indicated in figure 21 by the straight part of the TS curves of stations 78, 8, and 26 which runs from about T = 17° C., S = 35.2 ‰ to T = 7° C., S = 34.6 ‰. Near the equator this water occupies the depth range between 50 m and 500 m with only a thin layer of Equatorial Surface Water above it. This water will be called the Equatorial Subsurface Water. Its comparatively long residence time in subsurface layers

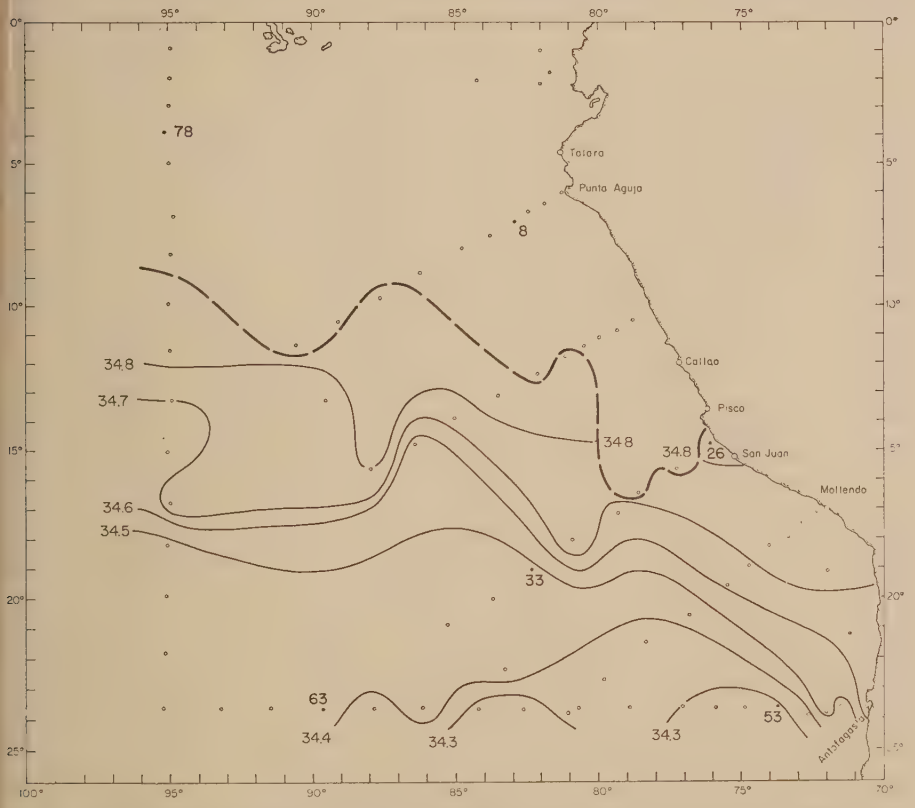


Fig. 22. Distribution of salinity ($^{0}/_{00}$) in the salinity minimum of the Subantarctic Water. The heavy broken line indicates the northern limit of the penetration of this water. Stations, with their numbers, for which a TS diagram is shown in figure 21 are denoted by ●.

causes the development of an oxygen minimum in this water mass, so that it is characterized by relatively high salinity and extremely low oxygen content. The accumulation of this Equatorial Subsurface Water in the eastern tropical Pacific Ocean and off Peru seems to be of major importance for the hydrography of the region, but it has received little attention so far.

It may be speculated that the accumulation of this subsurface water in the eastern tropical Pacific Ocean is a result of the Equatorial Undercurrent transporting about 30 million $m^3$/sec to the east, reaching as far as the Galápagos Islands and disappearing there (Knauss, 1960). It is likely that part of its water

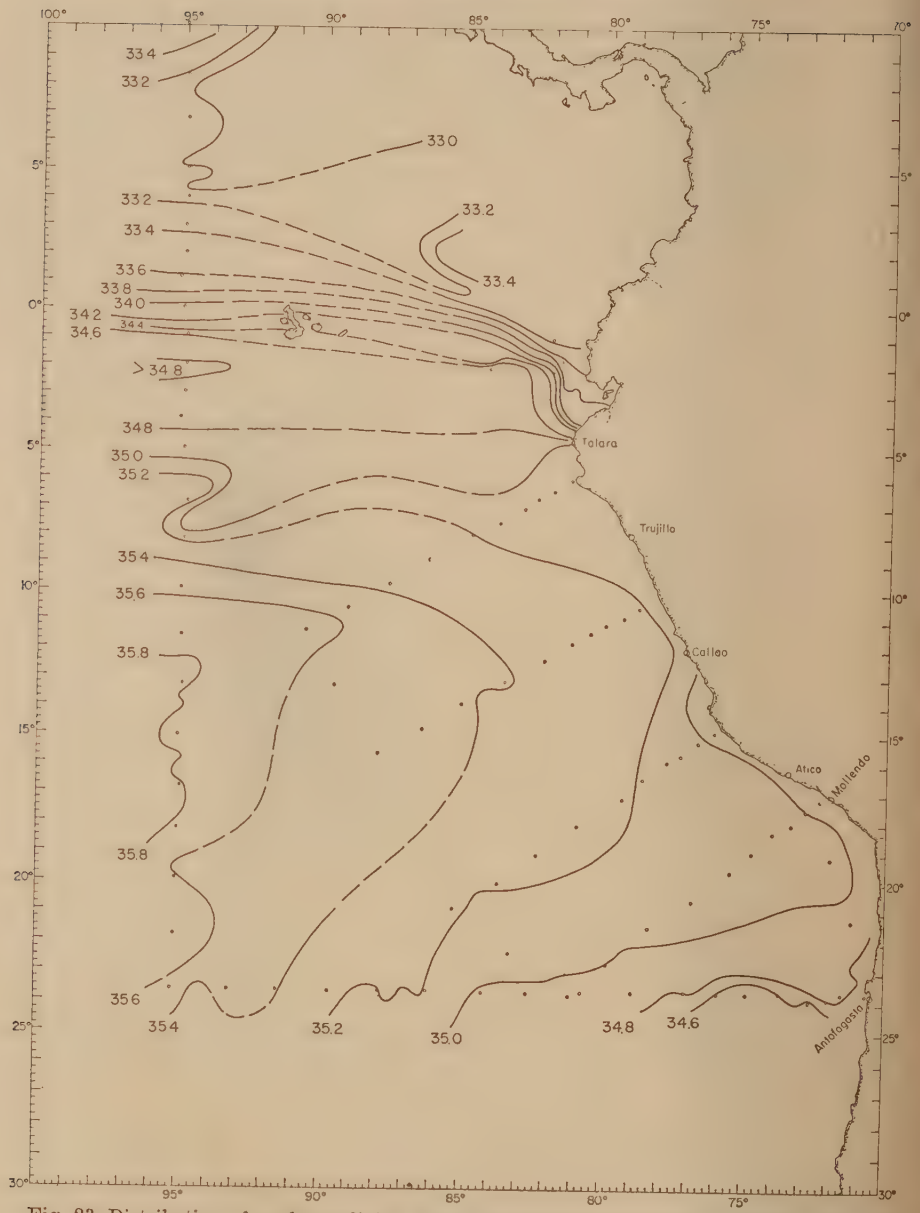


Fig. 23. Distribution of surface salinity ($^0/_{00}$) during Step-I Expedition as drawn from surface samples at hydrographic stations and underway samples. Broken lines represent interpolation.

finally supplies the upwelling in the northern parts of the Peruvian coast. It would be very desirable to investigate this possibility.

In the range of the Peru Coastal Current a subsurface salinity minimum is found in the discontinuity layer near 100 m depth (station 53). This minimum is due to the northward spreading of Subantarctic Surface Water sinking along the Subtropical Convergence, but in the region under consideration it is always found below the surface overlaid by Subtropical Surface Water of slightly higher salinity. Only in the southern parts of the Peru-Chile Current (not discussed in this paper) is this water found at the surface. The salinity minimum is also found underneath the Subtropical Surface Water in the range of the Peru Oceanic Current and the Peru Countercurrent (stations 63 and 33) in 200–300 m depth. The extent of its spreading is charted in figure 22, where the salinity in the salinity minimum is given. Along the coast it penetrates to about 15° S. and farther offshore to 10° S. North of this line a salinity minimum is no longer present, and the TS curves follow those at stations 78 and 8. The thickness of the layer of Subantarctic Water is usually less than 100 m and it is situated in the lower part of the discontinuity layer.

As the Subantarctic Water spreads north with the surface circulation, a layer of Equatorial Subsurface Water remains underneath and a salinity maximum appears on top of this layer, as seen in the TS curves at stations 33, 53, and 63. Because of the low oxygen content of the Equatorial Subsurface Water, this layer is also characterized by an oxygen minimum. This salinity maximum and oxygen minimum can be traced as far south as 35° S. along the coast, as shown by Gunther (1936) and Wooster and Gilmartin (1961).

The distribution of water masses, as outlined above, shows close relations to the circulation but offers in addition important conclusions about the origin of the waters in the upwelling area, which will be discussed next. In the range of the Peru Coastal Current the inflow of Subantarctic Water from the south, with a thin layer of Subtropical Surface Water above it, is restricted to the upper 200 m, as can be seen from figure 15. Below this depth a weak southward flow of Equatorial Subsurface Water takes place. This flow to the south is concentrated in the Peru Undercurrent right along the coast and in the Peru Countercurrent farther offshore (fig. 20). The Subantarctic Water penetrates with the Peru Coastal Current only as far north as 15° S., as shown in figure 22. The hydrographic situation at this position (station 26) shows that already in 100 m depth a salinity maximum is found which is characteristic of the Equatorial Subsurface Water. Consequently Subantarctic Water can only contribute to upwelling to the south of 15° S., and here the salinities of the upwelling water are usually low (fig. 23). This observation also demonstrates that the actual upwelling is a very shallow process, as was found previously from calculations of the ascending velocities (section on Vertical Flow).

In the range of the Peru Oceanic Current, which extends to about 700 m depth, the Subtropical Surface Water as well as the Subantarctic Water are flowing north and turn to the west. Equatorial Subsurface Water, which is still found in the lower portions of this current, rapidly loses its characteristics at distances from the coast of about 1,000 km and more. It is carried into the lower portions of

the Peru Oceanic Current by a flow toward the southwest and west, indicated in the layer between 300 m and 700 m depth (fig. 6). In this layer, water entering the region from the north off Punta Aguja flows south to about 17° S. and then turns west, leaving the region between 15° S. and 20° S.

In the coastal area between Punta Aguja and Pisco, the Equatorial Subsurface Water reaches right to the surface, as can be seen from the TS curve at station 8 (fig. 21). This curve resembles that of station 78 very closely; only the Equatorial Surface Water is not present. This water is kept in a more northerly position by the prevailing south winds in that area. The flow of the surface and especially of the subsurface water off Punta Aguja is, however, to the south, as can be seen from figure 15. Consequently the entire area between 5° S. and 15° S. and as far as 500 km offshore is filled with Equatorial Subsurface Water which is upwelling along the coast. This upwelling is again a very shallow process, but brings water of comparatively high salinity to the surface in contrast to the upwelling south of 15° S. (fig. 23). In lower layers water is descending, thus causing the enormous thickness of the oxygen minimum layer in this area.

Although the Antarctic Intermediate Water is found in the entire region, its presence seems to result more from the effect of horizontal mixing than of actual flow. This is supported by the east-west direction of the isohalines in the minimum, as well as by a strong meridional salinity gradient between 20° S. and 25° S., indicating a flow to the west and a boundary of its northward spreading. The layer between 600 m and 1,000 m depth is that of weakest horizontal movements, as shown in the section on the Three-Dimensional Field of Motion.

## CONCLUSION

The method developed in this paper and its application to the Peru Current show that the use of the geostrophic approximation together with the Ekman wind transports and the equation of continuity can be a powerful tool in analyzing the three-dimensional field of motion in the sea. Although the hydrographic situation observed during Step-I Expedition may only represent the conditions during a particular year, and care has to be exercised when generalizing the results, the coherence of the results and especially the agreement of the calculated circulation with the water-mass distribution indicate that the use of the equation of continuity in connection with geostrophic calculations can increase the usefulness of these calculations considerably and can lead to a better understanding of the three-dimensional field of motion. Although these calculations were carried out as an experiment, the results of the calculations seem to justify the application of the method in other regions of the oceans.

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# Vertical eddy viscosity in the Pacific Equatorial Undercurrent*

Klaus Wyrtki† and Edward B. Bennett‡

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**Abstract**—The observed velocities in the core of the Equatorial Undercurrent do not agree with those calculated from the pressure gradient according to Bernoulli's equation; thus it seems that friction is important in establishing the velocity distribution. The loss of energy due to friction in the current can be accounted for by a coefficient of vertical eddy viscosity $A = 3$ cm$^2$ sec$^{-1}$. Along the entire length of the Undercurrent about half of the potential energy is converted into kinetic energy and half dissipated by friction. Close to the Galapagos Islands, the velocity of the current decreases substantially due to the combined action of a retarding pressure gradient and of friction.

In the Pacific Ocean the Equatorial Undercurrent flows east as a subsurface current with a velocity maximum at the equator, as shown by Knauss (1960) and Montgomery and Stroup (1962). There is also an east-west pressure gradient along the equator with higher sea level in the west (Montgomery and Palmen, 1940; Knauss, 1963). Because the horizontal component of the Coriolis force vanishes at the equator, this pressure gradient should accelerate the current, which flows ' downhill.' The maximal observed velocity in the Undercurrent is about 160 cm/sec, which according to Bernoulli's equation would be established by a pressure difference of only 12·8 dyn cm. According to the observations shown by Knauss (1962) the sea surface west of 180° is approximately 60 dyn cm higher than near 100°W. Although this difference is smaller at the depth of the core of the Undercurrent, it is still in excess of the pressure difference required by Bernoulli's equation. Moreover, the velocity of the Undercurrent decreases substantially when approaching the Galapagos Islands, but the increase in dynamic height is small. In the case of Bernoulli's equation, the pressure should increase to the same value from which the current started. These arguments lead to the conclusion that friction must be a decisive factor in establishing the observed current velocity. In the following, the value of the coefficient of vertical eddy viscosity will be derived from observations of the pressure and velocity distribution.

The equation for the zonal component $u$ of a stationary motion is given by

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial x} + A\frac{\partial^2 u}{\partial z^2} \tag{1}$$

where $u$, $v$, and $w$ are the velocity components in the $x$-, $y$-, and $z$-directions, $x$ is positive east, $y$ north, $z$ downwards. $\rho$ is the density, $p$ the pressure, $f$ the Coriolis parameter and $A$ the coefficient of vertical eddy viscosity, which is assumed constant. Lateral

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†Scripps Institution of Oceanography, Institute of Marine Resources, La Jolla, California.
‡Inter-American Tropical Tuna Commission, La Jolla, California.

friction may be neglected. At the equator the Coriolis parameter vanishes, $f = 0$, and the zonal velocity $u$ is assumed to have a maximum in accordance with the observations, thus $\partial u/\partial y = 0$. Under these conditions equation (1) reduces to

$$u \frac{\partial u}{\partial x} + w \frac{\partial u}{\partial z} = - \frac{1}{\rho} \frac{\partial p}{\partial x} + A \frac{\partial^2 u}{\partial z^2} \tag{2}$$

The zonal velocity $u$ in the Undercurrent has also a distinct maximum in the vertical direction where $\partial u/\partial z = 0$. In order to compare the observed velocity in the velocity maximum with the pressure gradient determined from hydrographic observations, it is necessary to estimate the value of $\partial^2 u/\partial z^2$ at the depth of the velocity maximum. The vertical distribution of $u$ can be approximated by the function.

$$u(x, z) = u_m(x) \frac{z - a}{l} e^{1 - \frac{z-a}{l}} \tag{3}$$

where $a + l = z_m$ is the depth of the velocity maximum, $a$ the depth of the boundary between the Undercurrent and the surface flow to the west, where $u = 0$, and $l$ the distance between that boundary and the velocity maximum, as shown in Fig. 1. To demonstrate the agreement of the function (3) with observed current profiles the values of $u/u_m$ as function of $z/l$ at four stations are plotted in Fig. 1. These

Fig. 1. Function used to approximate the vertical distribution of velocity $u$ in the Undercurrent, and observed values of $u/u_m$ at four stations plotted against $z/l$.

values fit the curve reasonably well if the errors of the current measurements and depth determination are considered. It follows directly from (3) that at the depth of the velocity maximum where $z = a + l$,

$$\frac{\partial u}{\partial z} = 0 \text{ and } \frac{\partial^2 u}{\partial z^2} = - \frac{u_m(x)}{l^2}$$

With this approximation for $\partial^2 u/\partial z^2$, equation (2) becomes

$$u \frac{\partial u}{\partial x} = - \frac{1}{\rho} \frac{\partial p}{\partial x} - A \frac{u}{l^2} \tag{4}$$

being a differential equation for the velocity in the velocity maximum of the Undercurrent. Like Bernoulli's equation, (4) can be integrated along a streamline. This integration can be performed with respect to $x$ if the acceleration potential (MONTGOMERY and SPILHAUS, 1941) at the core of the Undercurrent is used instead of the pressure at a level surface as shown by MONTGOMERY (1937). The integration gives

$$\tfrac{1}{2} u^2 = \tfrac{1}{2} u_0^2 + \frac{1}{\rho}(p_0 - p) - \int_0^x \frac{Au}{l^2}\, dx \qquad (5)$$

This equation states that at the current maximum the kinetic energy per unit mass equals the loss of potential energy less the energy dissipated by friction. It will be used to determine the average value of $A$ near the high velocity core of the Undercurrent from observations of pressure and velocity.

In 1958 the Dolphin Expedition of the Scripps Institution of Oceanography made hydrographic and current observations along the equator between 140°W and the Galapagos Islands at every 3 degrees of longitude (KNAUSS, 1960). From the observations of the vertical current profiles the depth of the velocity maximum and the value of the parameter $l$ were determined. The depth of the velocity maximum varied between 98 and 40 m, the value of $l$ between 86 and 35 m. Although the depth of the velocity maximum changes significantly, the maximum remains reasonably close to a surface of constant specific volume. The specific volume anomaly at the velocity maximum changes from about 300 cl/ton in the western part of the section to 250 cl/ton in the eastern part as shown in the lower part of Fig. 2.

In spite of this slight change the flow in the Undercurrent will be considered as quasi-isentropic. To determine the pressure, the acceleration potential at the 280 cl/ton surface has been calculated (MONTGOMERY and SPILHAUS, 1941) and is shown in Fig. 2. The calculations were made relative to 350 db because the surfaces of constant specific volume appear to be level at this depth and the velocity of the Undercurrent becomes zero. MONTGOMERY and STROUP (1962) have used the depth of the 300 db surface for their calculations. It should be mentioned that the curves of the acceleration potential of all surfaces between 300 and 240 cl/ton are almost identical to that shown in Fig. 2. Moreover the dynamic topography of the 75 db relative to the 800 db surface gives the same pressure distribution within $\pm$ 1 dyn cm.

In order to obtain a first estimate of the value of $A$, the function

$$\frac{\rho}{2} u_0^2 - \rho \int_0^x \frac{Au}{l^2}\, dx = \frac{\rho}{2} u^2 + (p - p_0) \qquad (6)$$

has been calculated according to (5) using the acceleration potential of the 280 cl/ton surface and the observed velocities $u$ in the velocity maximum. The left hand side of equation (6) shown in Fig. 2, which is equivalent to the energy dissipation by friction, fluctuates considerably but decreases toward the east by approximately 9000 ergs over a distance of 5300 km. With an average velocity $u = 135$ cm/sec and an average $l = 50$ $m$, an approximate value of the coefficient of vertical eddy viscosity is $A = 3{\cdot}2$ cm$^2$ sec$^{-1}$.

The fluctuations of the energy dissipation function are chiefly due to the fluctuations of the observed maximal velocity in the current. These current observations

were made from a ship often drifting with as much as 1 knot relative to a buoy anchored in deep water. KNAUSS (1960) states that the standard error of the velocity observations is between 11 and 18 cm/sec but that not many errors will exceed ± 30 cm/sec.

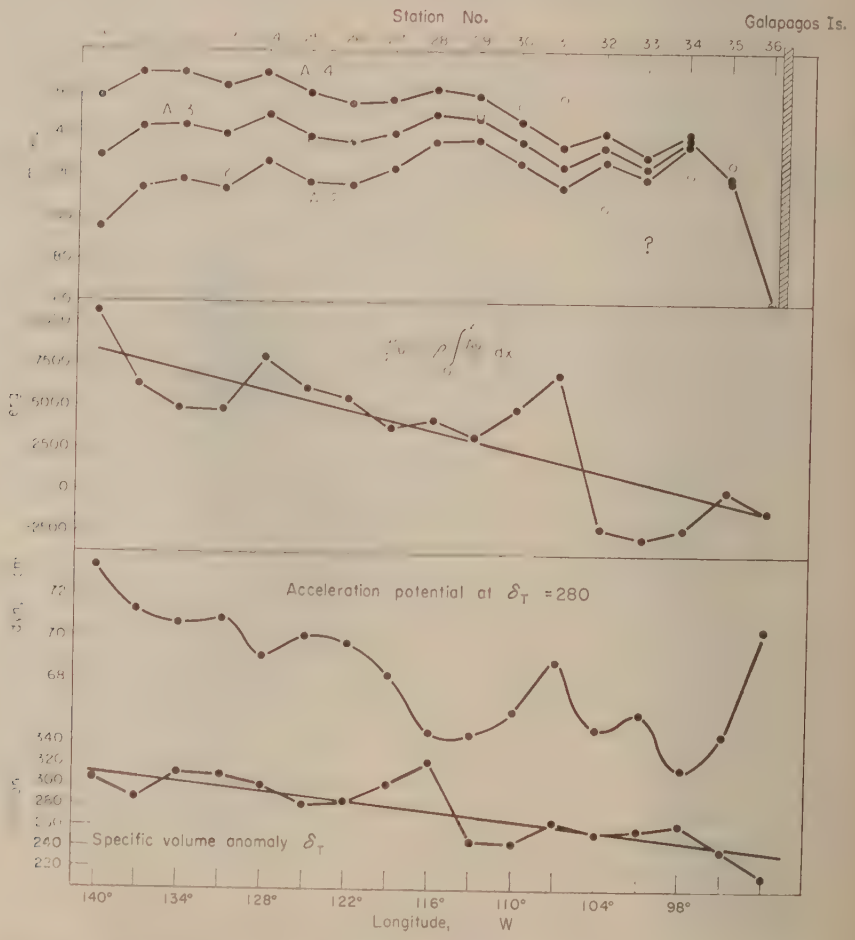


Fig. 2. Top : Velocity distribution in the core of the Equatorial Undercurrent calculated according to equation (5) for three values of the coefficient of vertical eddy viscosity A. Circles show observed velocities in the velocity maximum
Centre : Energy dissipation function calculated from observations according to equation (6).
Bottom : Acceleration potential at the surface where $\delta_T$ = 280 cl/ton, and specific volume anomaly at the depth of the velocity maximum.

After this approximate value of $A$ has been determined, equation (5) has been solved for $u$ by numerical integration using the acceleration potential of the 280 cl/ton surface and the values of $l$ determined for each station. The integration was started from station 36 at the Galapagos Islands where $u_0$ = 61 cm/sec. The results are shown for three different values $A$ = 2, 3 and 4 cm² sec⁻¹ in the upper part of Fig. 2

together with the observed current velocities which are indicated by circles. Two doubtful measurements have been indicated by a question mark. The best agreement is reached with a value $A = 3$ cm$^2$ sec$^{-1}$ which requires a starting velocity of 129 cm/sec at 140°W. The deviations of the observed maximal velocities from the calculated values are in most cases within the limits stated above. The largest discrepancies are between stations 31 and 32 where the velocity decreases considerably in spite of an accelerating pressure gradient. There is no obvious explanation for this behaviour. On the other hand, the sharp drop of the specific volume anomaly at the velocity maximum between stations 28 and 29 does not coincide with irregularities in the velocity distribution. Errors introduced from the hydrographic observations through the calculation of the acceleration potential are less severe because an error of 1 dyn cm is equivalent to an error of only 8 cm/sec at a velocity of 125 cm/sec.

Between stations 15 and 31 the observed velocity increases only slightly; thus, pressure gradient and friction are almost balanced. Close to the Galapagos Islands, on the other hand, the considerable decrease of the velocity is due to the combined action of pressure gradient and friction for both of them retard the current.

The value $A = 3$ determined for the coefficient of vertical eddy viscosity in the core of the Undercurrent cannot easily be compared with other estimates of this coefficient. ARTHUR (1960) estimates an average value of $A = 10$ cm$^2$ sec$^{-1}$ between the surface and the depth of the velocity maximum, but it may be assumed that $A$ is much larger in the wind-driven surface layer than near the core of the Undercurrent where a strong density gradient reduces its value. MONTGOMERY (1939) calculates for the discontinuity layer of the tropical Atlantic Ocean a maximal value of 0·4 cm$^2$ sec$^{-1}$ for the coefficient of vertical eddy conductivity, which is derived from observations of the salinity distribution. WYRTKI (1963) calculates for the very strong thermocline in the Costa Rica Dome in the eastern tropical Pacific Ocean a coefficient of vertical eddy conductivity of 0·14 cm$^2$ sec$^{-1}$ from the temperature distribution. The corresponding coefficients of vertical eddy viscosity should, however, be considerably higher in both cases.

A frictional effect corresponding to that of vertical eddy viscosity $A_v$ could be due to lateral eddy viscosity $A_h$ if $A_h/L^2 = A_v/l^2$ and where $L$ is the characteristic width of the Undercurrent. With $L = 150$ km, $l = 50$ m and $A_v = 3$ cm$^2$ sec$^{-1}$, it follows that $A_h = 2{\cdot}7\ 10^7$ cm$^2$ sec$^{-1}$. Only if $A_h$ comes close to this value would lateral friction be of importance in the Undercurrent. STOMMEL (1955) follows from current observations that $A_h = 9 \pm 5\ 10^5$ cm$^2$ sec$^{-1}$ in the Gulf Stream. If a similar value is assumed for the Undercurrent, it is evident that the effect of lateral eddy viscosity is more than an order of magnitude less than that of vertical eddy viscosity.

After the balance between pressure gradient, acceleration and friction has been established for the eastern part of the Undercurrent between 140°W and the Galapagos Islands, it seems to be interesting to pursue this balance along the entire length of the current. At the surface the average pressure gradient between 110°W and 160°E is 6·4 $10^{-5}$ g cm$^{-2}$ sec$^{-2}$ as taken from a figure by KNAUSS (1963). Over this distance, but especially between 100° and 160°W, the pressure gradient seems to be constant. For this discussion the Undercurrent will be assumed to be isentropic. The isosteric surface closest to the high velocity core of the Undercurrent between 110° and 140°W is that of $\delta_T = 280$, as shown above. The average pressure gradient in this surface is 2·5 $10^{-5}$ g cm$^{-2}$ sec$^{-2}$, being less than half of the pressure gradient at the surface.

With the assumption that this pressure gradient is effective and constant along the entire length of the current, equation (4) can be integrated with respect to $x$. With $u = 0$ at $x = 0$, the starting point of the current, it follows

$$\frac{\rho}{2} u^2 = -\left(\frac{\partial p}{\partial x}\right) x - \frac{\rho A}{l^2} \int_0^x u \, dx \tag{7}$$

The integration has been carried out with the values $A = 3$ cm$^2$ sec$^{-1}$ and $l = 50$ m, which were used previously. The result is shown in Fig. 3. Within the first 10 degrees of longitude the velocity in the core of the Undercurrent increases rapidly to about 70 cm/sec and from there on more slowly. Velocities exceeding 150 cm/sec are reached after the current has travelled over a distance of 90 degrees of longitude. The velocities observed between 140° and 110°W agree best with this curve if the origin of the Undercurrent is placed at 160°E. This prediction should be tested by observations.

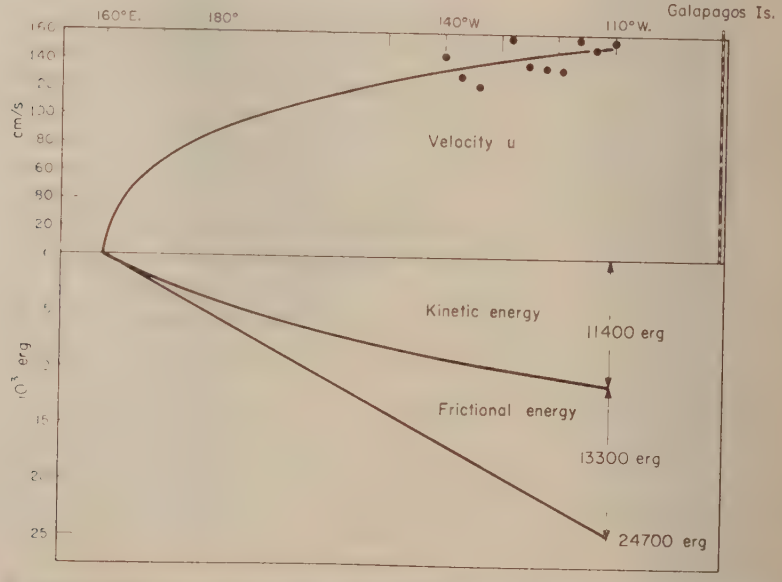


Fig. 3. Velocity, kinetic energy and energy lost by friction in the Equatorial Undercurrent. Dots indicate observed velocities in the core of the Undercurrent between 140° and 110°W.

The energy balance shown in the lower part of Fig. 3 demonstrates that in the western part of the current the potential energy is chiefly converted into kinetic energy while in the eastern part of the current the dissipation of energy due to friction is more important. Between 160°E and 110°W the drop of potential energy amounts to 24,700 ergs, of which 11,400 ergs are converted into kinetic energy and 13,300 ergs are dissipated by friction. This balance demonstrates the importance of friction for the establishment of the velocity distribution in the Undercurrent.

If a constant pressure gradient would be effective over a distance long enough,

a maximal value $u = u_\infty$ would be reached asymptotically. This value can be calculated from (4) by taking $\partial u/\partial x = 0$. With the same values as used above it follows that $u_\infty = 208$ cm/sec. This value demonstrates that the current is still far away from reaching its asymptotic velocity.

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